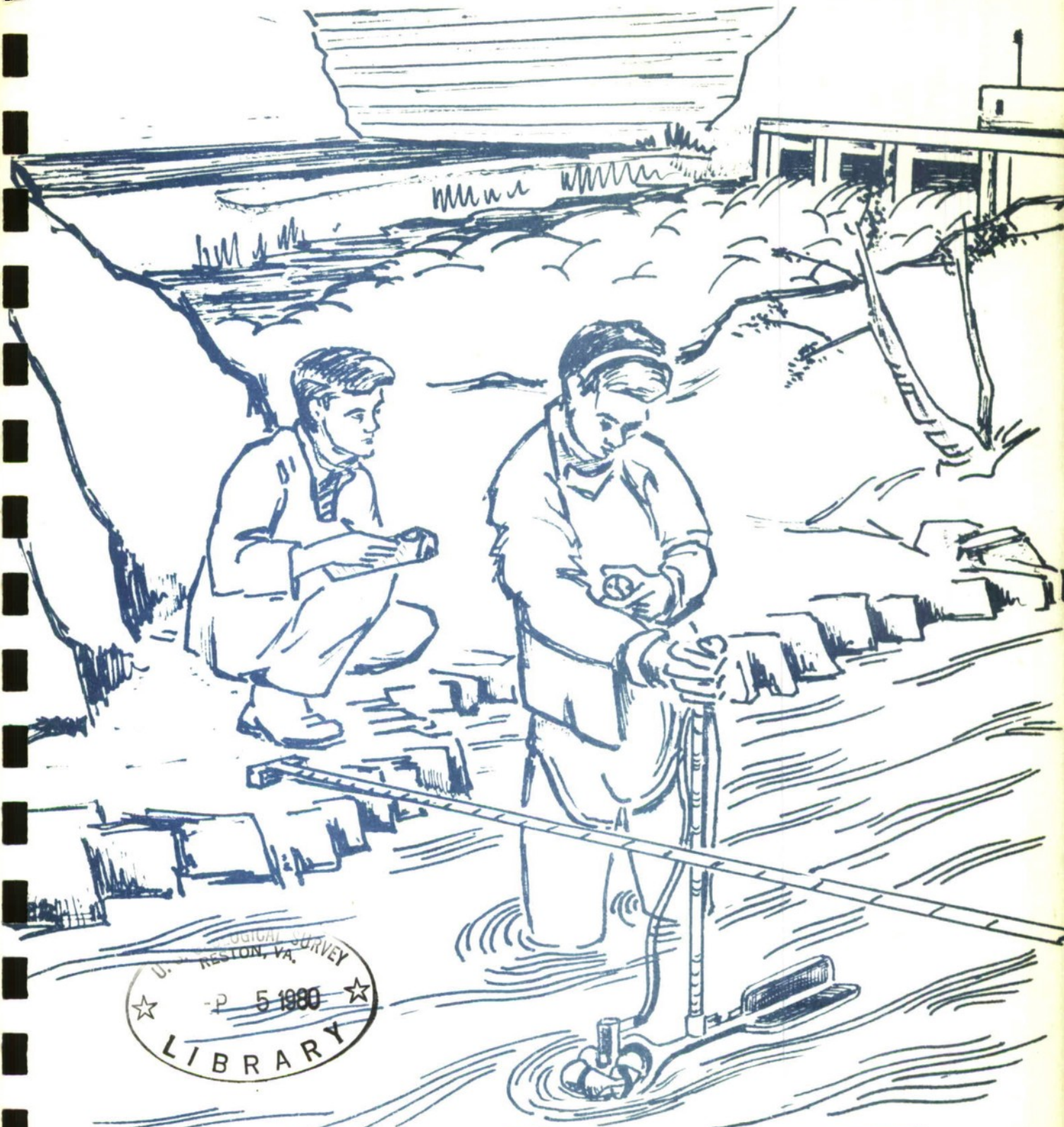


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HYDROLOGY TRAINING MANUAL



BASIC STREAMGAGING

MINISTRY OF AGRICULTURE

HYDROLOGY TRAINING MANUAL

Number 1 - Basic Streamgaging

Prepared by the
United States Agency for International Development
Mission to Afghanistan
in cooperation with the
Water and Soils Survey Department
of the
Ministry of Agriculture
Royal Government of Afghanistan

Kabul
1966

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Introduction

Part 1.0

Stream gaging is the process of measuring the depths, areas, velocities and rates of flow of water in natural or artificial channels. Water is an essential part of plant and animal life, and without it all living things would perish. The demand for water is increasing due to the growth in population and the higher standard of living in the world today.

Water being a necessity and being available in limited quantities make it important that the supply available in surface streams be known. This information proves invaluable in studies of municipal water systems, irrigation projects, flood control, industrial processes, water power development, pollution control, bridge design, water rights, drainage, recreation, and many others.

This training manual describes the methods, procedures, instruments, and equipment used to measure the flow of water in open channels. The manual is primarily for use in training new hydrographers, but it does contain information on equipment and procedures which is of importance to experienced hydrographers.

Some sections that were omitted in the first printing of this training manual have now been included with the exception of descriptions of certain equipment that are still considered too advanced for the present level of competence of the Afghan technician.

The information contained in this training manual has been largely taken from the U.S. Geological Survey Stream Gaging Manual compiled by T. J. Buchanan of that organization and represents the combined efforts of hundreds of engineers and hydrologists over a period of many years. Where necessary, changes were made to fit Afghanistan conditions.

A.O. Westfall, Hydrologic Advisor
U.S. Geological Survey

Gaging stations

Part 2.0

A gaging station is a structure in or near the stream channel which indicates or records the height of the water surface in the stream. The station may also include a structure from which discharge measurements may be made and a stabilized section of stream channel called the control.

A nonrecording gaging station consists of a staff or some other device graduated in feet and hundredths or meters and centimeters. The height of the water surface is read by an observer one or more times daily and the readings recorded. Recording gaging stations utilize various types of recorders and require recorder shelters and facilities for transmitting stream stage to the recorder.

Gaging stations are further classified as stage stations and discharge stations. Both types provide stage records. A discharge station also provides a continuous record of discharge through use of a relation between stage and the corresponding discharge as measured regularly at the gaging station.

From the standpoint of design and operation, gaging stations are classified in three types which are described in the following lessons.

Types of gaging stations

Part 2.1

There are three main types of gaging stations in use at the present time:

1. Stilling well
2. Non-recording
3. Partial record

The type of gaging station to be used at a site depends on the following factors:

1. Classification of station (areal or water management)
2. Funds available
3. Location and climate

The classification of a station will have a great bearing on the type station used. Classification will determine the length of time the station will be operated and the type and amount of data to be collected. If a station is to be operated for many years a masonry

stilling well type station would probably be used whereas if a station is to be operated only for a short time, a corrugated pipe stilling well station, a nonrecording station, or a partial record station would be used.

Stilling well type station

Part 2.1.1

In this type the water-surface elevation in the stream is transferred through intakes to a stilling well in the channel or in the bank. The well supports a recorder shelter. Water level in the well is transmitted by float and tape to the water-stage recorder.

The stilling well protects the float and makes it possible to obtain accurate readings of stage with reference gages. The stilling well dampens the fluctuations in the stream caused by wind and turbulence. Stilling wells are constructed of masonry, reinforced concrete, concrete pipe, and occasionally wood. Stilling wells are usually placed in the bank of the stream but oftentimes they are placed in the stream attached to bridge piers or abutments. The stilling well should have sufficient height that its bottom is at least a foot below the minimum stage anticipated and its top above the 50-year flood. The inside of the well should be of sufficient size to permit free operation of all the equipment to be installed. Normally a pipe 4 feet in diameter or a well with inside dimensions 4 feet by 4 feet is of satisfactory size, but pipes 18-inches in diameter have been used for temporary installations where a conventional water-stage recorder was the only equipment to be installed. The 4-foot well provides ample space for the hydrographer to enter the well to clean it or to repair equipment. The smaller metal wells and the deep wells should be provided with doors at various elevations to facilitate cleaning and repairing.

The stilling well should have a bottom and when placed in the bank of the stream the well should be watertight so that ground water cannot seep into it.

Means may be needed to prevent the formation of ice in the well during cold weather. The three means used are: (1) sub floors, (2) heating, and (3) oil.

Subfloors are effective if the station is placed in the bank and has plenty of fill around it. The subfloor is built in the well below the frost line in the ground, and as long as the stage remains below the subfloor ice will normally not form in the well. Holes are cut in the subfloor for the recorder float and weights to pass through and

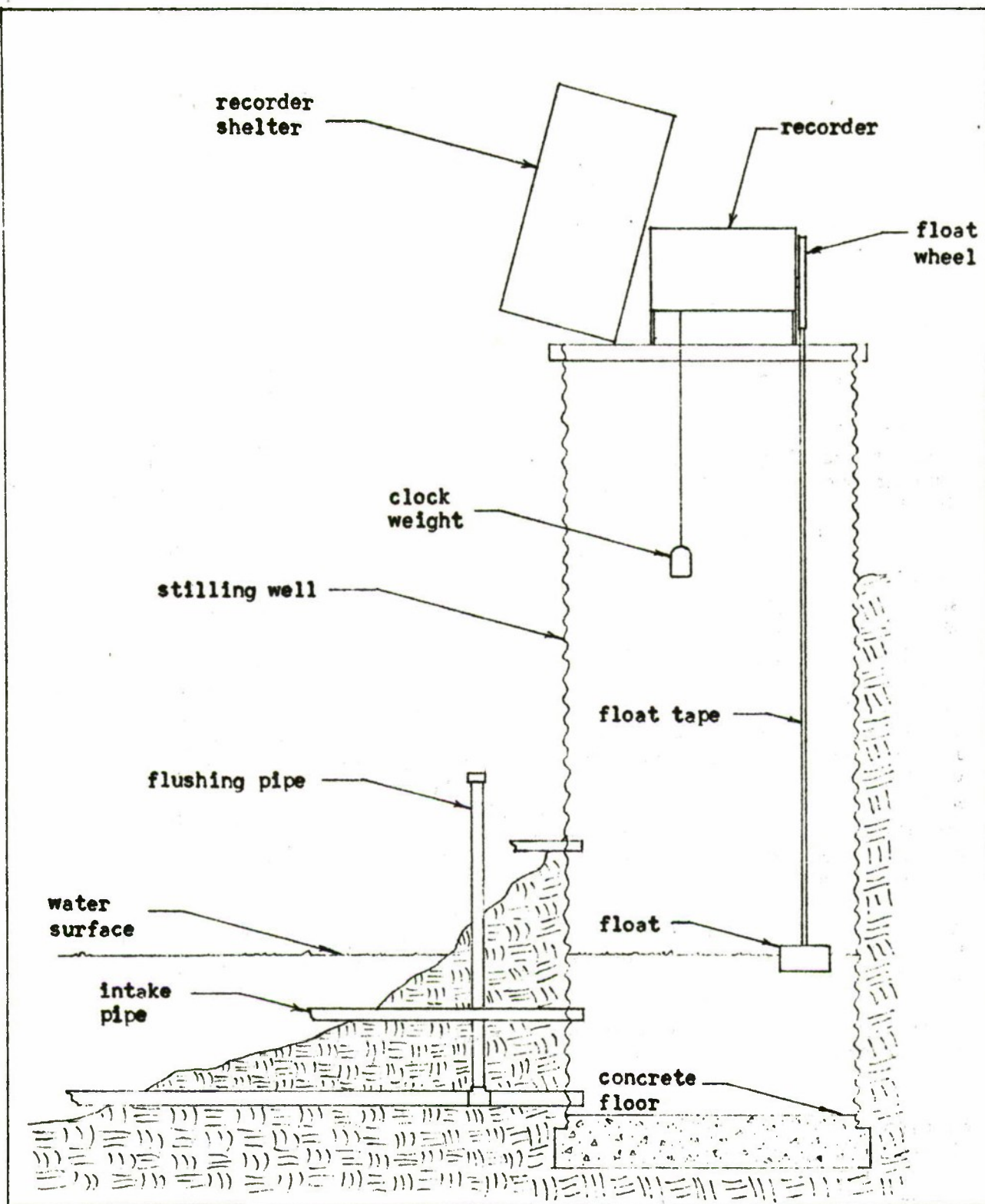


Figure 1.--Typical stilling well type station.

then removable covers are placed over the float holes. The advantage of using subfloors is that there is no operation cost as there is with heaters and there is no mess as there is with oil.

The use of oil in the prevention of ice in stilling wells is accomplished in two ways: (1) where the well is small and leakproof the oil may be poured into the well, and (2) where the well is large or not leakproof a tube of sufficient diameter to accommodate the recorder float is placed in the well, and oil, usually kerosene, is put in the tube. The oil tube should be of sufficient length to operate throughout the range in stage expected during the winter.

Water from the stream enters and leaves the stilling well through the intake so that the water in the well is at the same elevation as the water in the stream. If the gaging station is placed in the stream the intake consists of holes drilled in the stilling well and if the gaging station is placed in the bank the intake consists of a length of pipe connecting the stilling well and the stream. The intake should be at an elevation at least 0.5-ft lower than the lowest expected stage in the stream, and at least 0.5-ft above the bottom of the stilling well so that if silt builds up in the bottom of the well it will not plug the intake.

Two or more pipe intakes are commonly installed at vertical intervals of one foot or so. During high water silt may cover the stream end of the lower intakes but the higher ones will function correctly.

If the velocity past the ends of the intake is high, drawdown of the water level in the stilling well may occur. In order to reduce this drawdown static tubes are often placed on the stream end of the intake pipe. The static tube consists of a short length of pipe attached to an elbow on the end of the intake pipe and extending downstream from the intake pipe in the same horizontal plane as the intake. The end of the static tube is capped and water enters or leaves through holes drilled in the static tube.

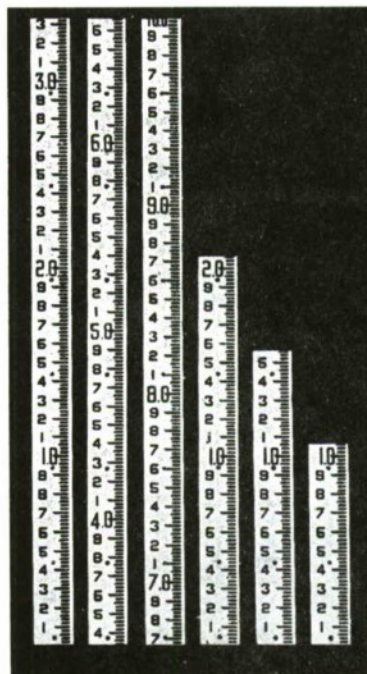
The instrument shelter that sits on top of the stilling well must be of sufficient size to accommodate the equipment to be placed in it. The shelters are constructed of almost every building material available and the material used depends on local custom and conditions. The most convenient type of shelter is one that the hydrographer can walk into and stand up in. A shelter with inside dimensions 4-ft x 4-ft with ceiling height 7-ft above the floor of the shelter is about the ideal size. Look-in type shelters are also used at sites where a limited amount of equipment is to be installed and a portable and cheap shelter is desired.



Style A—3 $\frac{1}{4}$ foot
Matching Sections.



Style M — 1-meter sections
used to assemble any
length of staff, with
separate figures for
numbering meter marks.



Style C—3 $\frac{1}{4}$ foot
Matching Sections for
long staffs; shorter
gages for weirs and
Parshall flumes.



Style E — 5-foot section
numbered at foot marks
with Porcelain Enamel
Iron Figure Plates.

Figure 2.--Non-recording staff gages.

Shelters should be well ventilated, especially in humid climates. The shelter should have a tight floor to prevent entry of water vapor from the well.

Gaging stations are equipped with reference gages in order to accurately determine the height of the water surface above gage datum in the stilling well and in the stream.

Non-recording type station

Part 2.1.3

A non-recording gage may consist of a graduated scale placed in the stream covering the full range in stage, or of equipment for measuring from a known elevation to the water surface with a weight suspended from a wire; observations being made once or twice a day to obtain a record of stream stage. A local resident is usually hired to make the observations. At some non-recording stations the gage has been placed in a stilling well to obtain more accurate readings.

Non-recording gages are cheap to install and supply reliable data if the observer is dependable and the stream stage does not change rapidly. Non-recording gages on flashy streams (those having rapid stage changes) often provide inaccurate records because two observations per day are not enough to properly define flood hydrographs. The two observations per day may be supplemented by the stage of the flood peak which can be obtained from a crest-stage gage.

The portable recording gages available today have lessened the use of non-recording gaging stations, but they are still used in some places where seasonal or other special periods of discharge data is desired and where dependable people are available as observers. Non-recording gages are sometimes used at recording gage sites when problems have been encountered and the recording gage is out of operation.

Gaging station controls

Part 2.2

A control is a natural constriction of the channel, a long reach of the channel, a stretch of rapids, or an artificial structure downstream from a gaging station that fixes the stage-discharge relation at the gage.

A control may be complete or partial, depending on the stage. The stage above a complete control is independent of the stage downstream from the control. A control which is complete at low stages may be

partial at medium stages and may not influence the stage at the gage at all at high stages. In the latter case, the effective control is a channel characteristic further downstream. A control either partial or complete may also be shifting. Most natural controls are shifting to a degree, but a shifting control is considered to exist where the stage-discharge relation changes frequently owing to impermanent bed or banks.

Controls, particularly low discharge controls, should be sensitive; that is, for any change in discharge a rather quick response to the change is reflected at the gage, and for a small change in discharge a relatively large change in stage occurs. A control is considered sensitive if a change in stage of 0.01 ft does not represent more than about a 2 percent change in discharge.

Natural controls

Part 2.2.1

A natural control is either a cross section that produces a fall or break in the water surface profile, or is a fairly long reach of channel. If the control is at a cross section it is commonly called a section control, and if a long reach of stream is the control it is called a channel control. A gaging station is located above a suitable natural control if possible, because artificial controls are expensive to construct and maintain.

The section type of control produces a noticeable fall in a short longitudinal profile of the stream, and usually consists of a ledge rock outcrop or a riffle. The first complete break in the slope at the upper end of the section control indicates the position of the upstream lip of the control and the point where the control is most effective in maintaining the stage-discharge relation.

The channel type of control is inconspicuous because of the lack of a break in the slope of the water surface downstream from the gage. At low discharges a channel control is generally due to the slope in the water surface that is produced by the frictional resistance of the stream bed.

It is not uncommon for different natural features in a stream to be the control at various stages. As the stage in a stream rises, the stage at the downstream side of the low-water control may rise faster than that upstream from the control. This may continue until the low-water control is no longer effective, at which time the governing control is some channel feature downstream from the low-water control, usually a reach of channel.

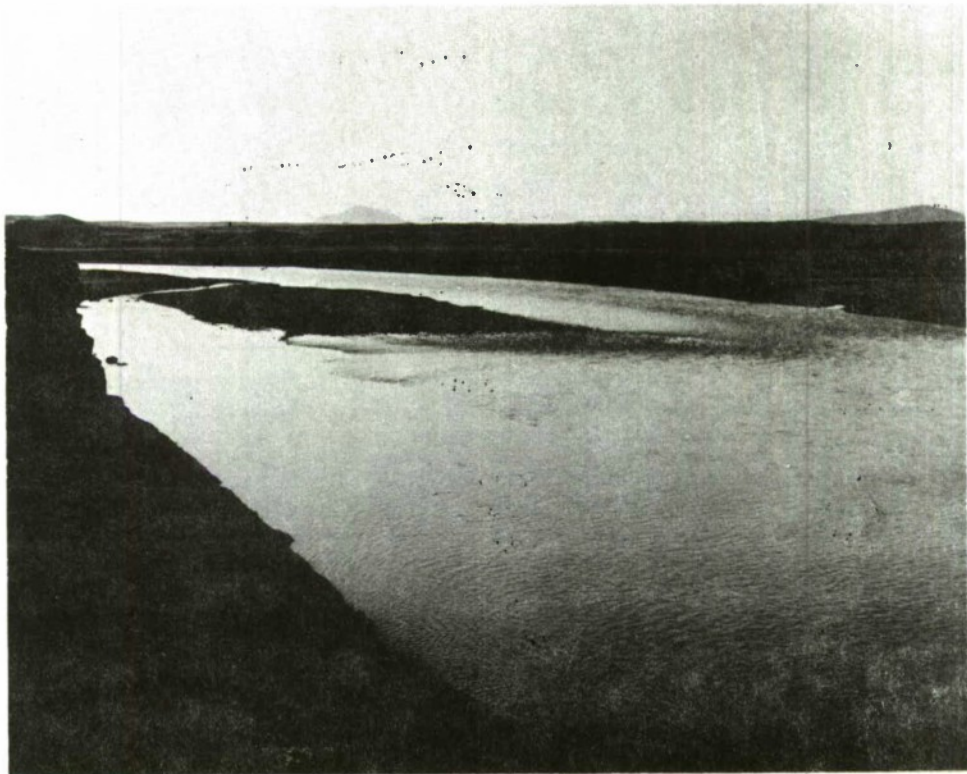


Figure 3.--Natural section control.

The definite positions of high-water controls, with the possible exception of artificial dams or natural waterfalls, are in general more difficult to recognize than those of low-water controls. The usual high-water control consists of a group of elements which ordinarily include one or more of such channel features as an abrupt bend in the channel, a contraction of the bed and banks, or a series of riffles.

Artificial controls

Part 2.2.2

Where natural conditions do not provide the stability or sensitivity required, artificial controls are used. Artificial controls are structures built in a stream channel to stabilize the channel at a section. They may be low dams, broad-crested weirs conforming to the general shape and height of the streambed, or flumes similar in design to the Parshall flume.

Four major points should be considered in the design of an artificial control:

1. The shape of the structure should permit the passage of water without creating undesirable disturbances in the channel above or below the control.
2. The structure must be of sufficient height to eliminate the effects of variable downstream conditions for the range in stage for which the control is to be effective.
3. The profile of the crest of the control should be designed so that a small change in discharge at low stages will cause a measurable change in stage.
4. The control should have structural stability and should be permanent.

Gaging station structures

Part 2.3

Three types of structures are used at gaging stations, (1) a gage house and possibly a well, (2) a structure for discharge measurements, and (3) an artificial control. The first item is needed if the stage is to be continuously recorded but the latter two items may or may not be needed depending on the measuring conditions at existing bridges and the natural control conditions at the site.

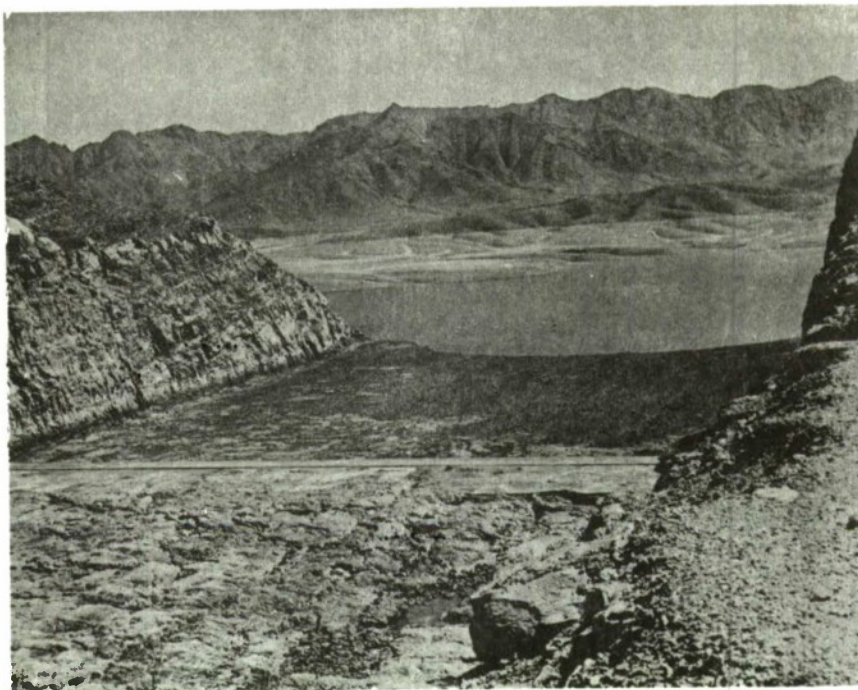


Figure 4.--Broad-crested weir.

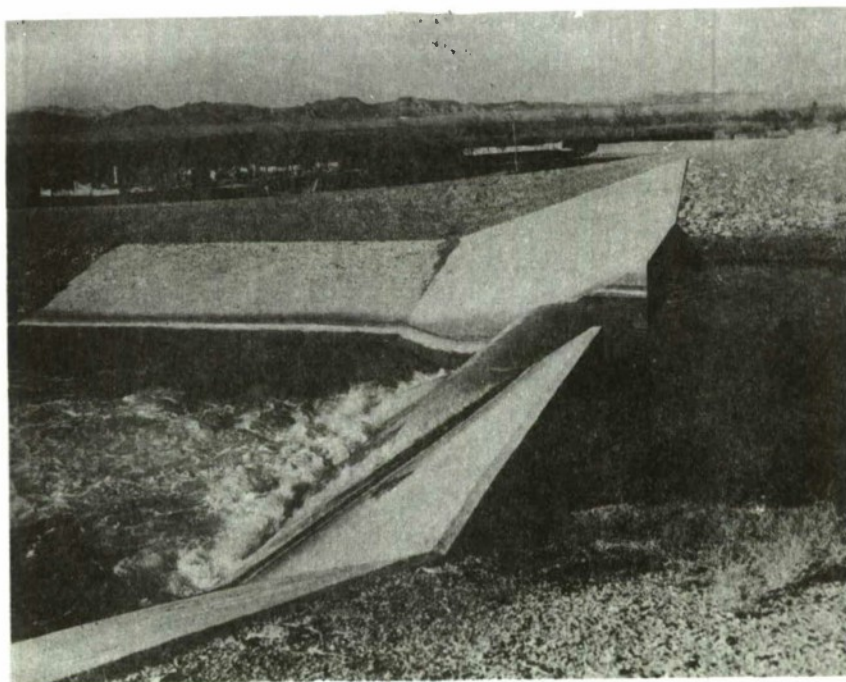


Figure 5.--Artificial control on a canal.

The construction of facilities for a gaging station should be very carefully planned to be certain the resulting structures are properly located, safe, and economical to operate and maintain.

Most of the construction work is done by our own personnel rather than contracting the work because the jobs are usually small and the cost of preparing detailed plans and of supervising construction would have to be added to the contract cost. However, the use of a contractor where practical frees our personnel for other work.

Gage house and well

Part 2.3.1

The type of gage houses and well will depend on:

1. Purpose of the record
2. Accuracy requirements
3. Permanence of the installation
4. Initial and operating costs
5. Instrumentation
6. Local conditions and customs

The gage wells are generally reinforced concrete or galvanized corrugated metal pipe in sizes ranging from 18-in diameter to 48-in diameter. The gage houses are generally of concrete, concrete block, corrugated metal pipe, prefabricated steel, or wood, and vary widely in size and other details.

Structures for discharge measurements

Part 2.3.2

Three main types of structures used for discharge measurements are cableways, highway bridges, and footbridges.

Cableways are supported by steel A-frames or H-columns, by wooden A-frames, or by side-hill anchorages. Steel structures are recommended. The cableways should be well anchored to concrete deadmen or ledge rock and the proper size and grade of wire rope should be used. USGS Circular 17 entitled, "Structures for Cableways" contains detailed plans and design information for cableway structures. In addition to the structures shown in Circular 17, the USGS has built A-frames using 4-inch or 5-inch galvanized steel pipe for the legs.

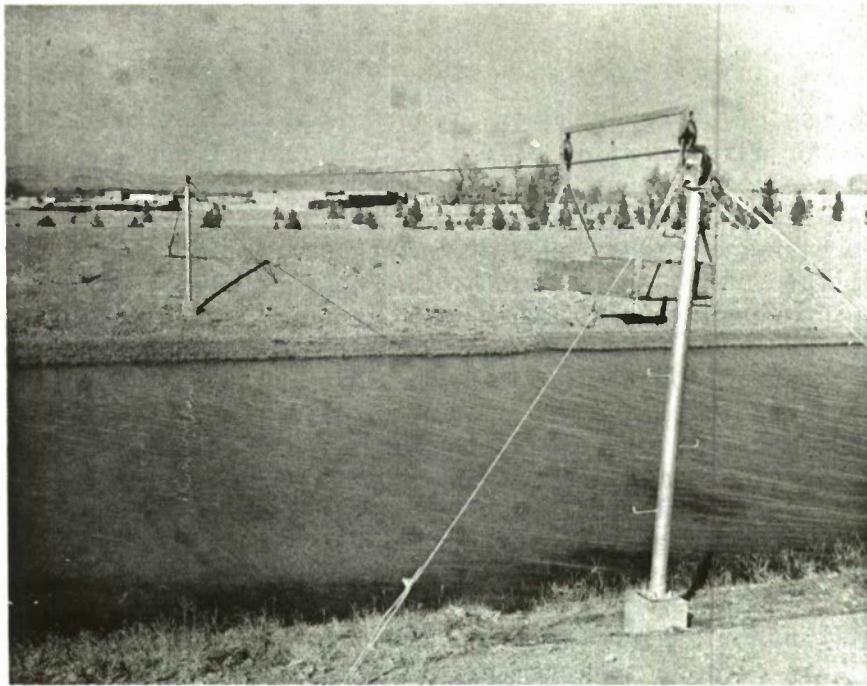


Figure 6.--Steel-pipe support for cableway.



Figure 7.--Side-hill anchorage.

The use of timber deadmen as anchorages is not recommended, as the cheaper first cost is offset by the cost of subsequent inspection and replacement, and the uncertainty as to its safety.

The highway bridges used in making streamflow measurements must be utilized as they are found. The only problem they present is to decide whether or not they will be serviceable for making discharge measurements. The advantage of using existing bridges is the saving in construction and maintenance costs that is associated with cableways, but this advantage is often outweighed by the poor measuring conditions at the bridge, the inconvenience associated with using some bridges, and the safety hazard caused by traffic conditions. A bridge that is used regularly for discharge measurements is stationed by marks at suitable intervals on the handrail or some similar feature of the bridge.

No standard design for footbridges for stream gaging is recommended because each footbridge installation presents its own particular problem. The type of footbridge used will depend on span, availability of material, stability of banks, accessibility of the site, type of equipment to be used, and funds available. Footbridges should be designed so that they give the hydrographer room to move about and to operate the current meter equipment conveniently.

Artificial controls

Part 2.3.3

Controls are usually constructed in accordance with channel conditions at the site but there are three distinctive control structures that are used by the USGS in natural channels when conditions are favorable. The three types are the Trenton, Columbus, and Asheville. The Asheville type is adapted for locations where the control can be placed on bedrock and where no apron is necessary whereas the other two types are adapted for most natural channels.

Artificial controls installed in canals and ditches consist of sharp-crested weirs and critical depth meters. The shape of the sharp-crested weirs are usually 90° V-notch, rectangular, or trapezoidal. Where there is sufficient available fall in a canal and the quantity of water to be measured is not too large, the weir is the most serviceable and economical type of control. V-notch weirs are used for the small discharges and the rectangular and trapezoidal weirs are used for larger discharges.

Where there is little available fall, or too much floating debris, or the discharge is too large for a weir, critical depth meters are used. One type of critical depth meter used is the Parshall flume or

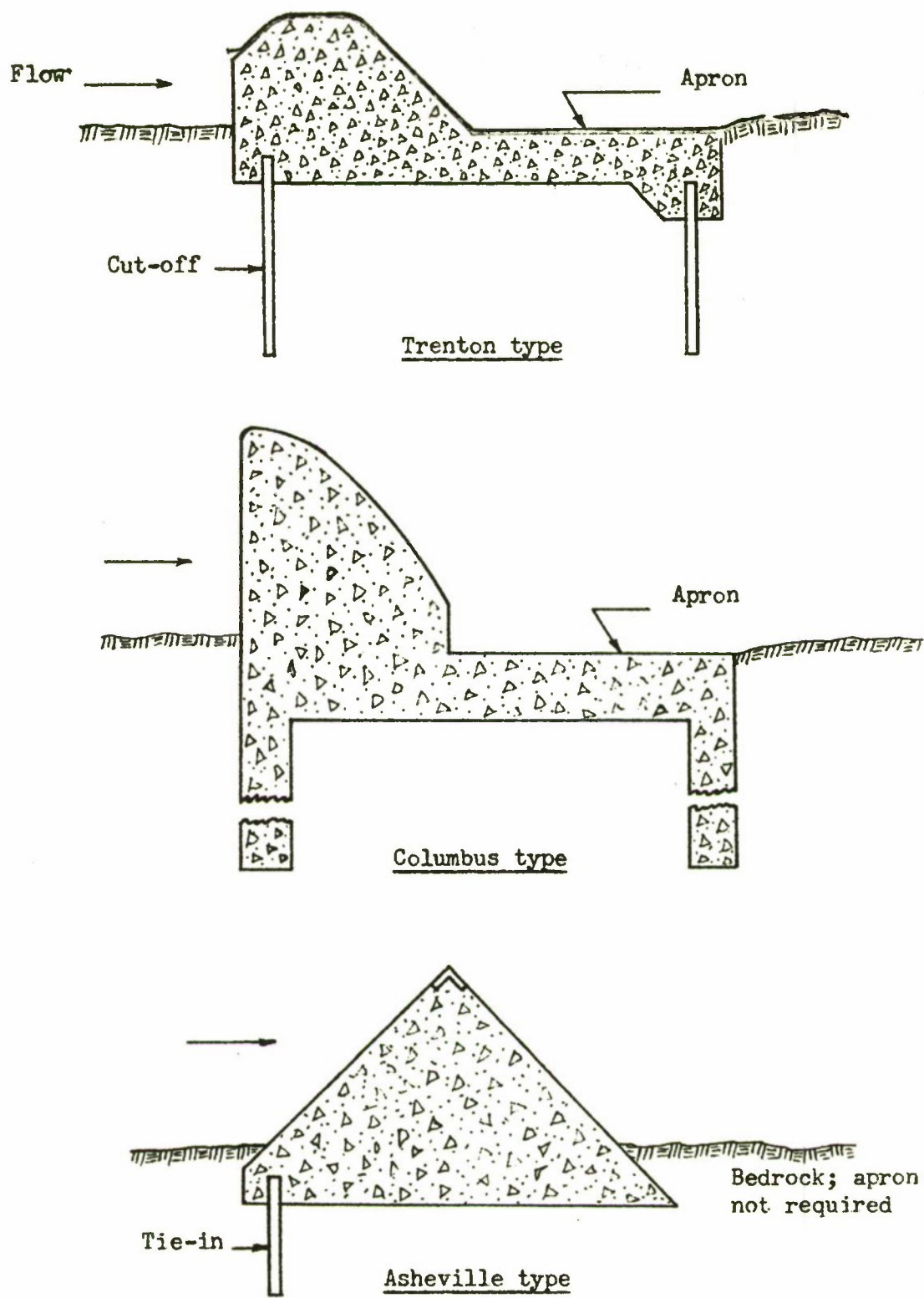


Figure 8.--Cross sections of three typical artificial controls.

some variation of this flume such as the Soil Conservation Service type H flume or the San Dimas flume. Debris and silt tend to be swept through the critical depth meters by the increased velocity which results from the constriction.

Gaging station site selection

Part 3.0

The first and one of the most important steps in obtaining accurate records of streamflow is the selection of the gaging station site. Sufficient time and study should be allowed for site selection when a new station is to be established so that the best possible site is chosen. Hasty selection of gaging station sites many times has meant the difference between good and poor records and the difference between economical and costly operation.

Gage location considerations

Part 3.1

The items to be considered when selecting a gaging station site are:

1. Control
2. Gage location
3. Availability of measuring sites
4. Accessibility
5. Economics

These five factors have to be weighed before a final decision is made on the location of a gaging station. A single visit to each proposed site is seldom enough. If possible all the proposed sites should be visited at various seasons of the year and at various stages of the stream. This is not often possible in practice but the sites should be visited under as many different conditions as the time allowed for establishment of the station permits.

When a gaging station is to be established on a stream, the available topographic maps of the area drained by the stream should be studied before any field reconnaissance is begun. The maps contain information on possible sites, regulation, location of tributaries, divided channels, steep banks, overflow areas, access roads, bridges, and other pertinent facts. As much preliminary investigation as possible should be done while still in the office for this information will prove invaluable during the field reconnaissance.

During the field reconnaissance all suitable sites for a gaging station in the reach of the stream where the station is to be established should be examined. The field reconnaissance should include a sketch and photographs of the hydraulic features at each possible site supplemented by the hydrographer's notes, comments, and evaluation of the site.

The control for a gaging station should be the first consideration during a field reconnaissance. The desirable control characteristics are:

1. Stability.
2. Sensitivity.
3. Freedom from backwater.
4. Same amount of water passing gage and control.

The ideal control should be stable so that there will be no appreciable shifting of the stage-discharge relationship. The possibility of and the necessity for modifying the natural control or building an artificial control should be explored. The control and reach of channel immediately upstream should be examined for evidence of previous major changes which might indicate future changes.

The control for a gaging station site should be sensitive so that a noticeable change in stage produces a noticeable change in discharge. The shape of the rating at a site should be estimated to aid in evaluating its sensitivity.

The control should be located so that it is as free from backwater as possible. There should not be a tributary entering the stream at or below the control. These tributaries leave deposits in the stream which effect the control and oftentimes they cause backwater on the control due to the staggered timing of flood peaks. The control should be examined to determine what effect ice and aquatic vegetation will have on the stage-discharge relationship. There should not be a lake, reservoir, or power pool in the reach of stream below the control that will cause backwater on the control of the selected site.

There should not be a tributary entering the stream between the gage and the control nor should there be an excessive amount of seepage between the gage and the control so that the amount of water passing the gage is less than that passing the control.

During the reconnaissance it is necessary to determine what feature will be the control at the various stages anticipated. At many sites two, three, and sometimes more different features are the control for a stream at different stages.

The gage location should have the following characteristics:

1. Be in a pool.
2. Be naturally protected from flood waters.
3. Be on a straight reach of the stream.

The gaging station should have its intake in the pool just upstream from the selected control. The intake orifice should not be located on the riffle or in a place where there is considerable fall.

The gage should be located so that there is natural protection from flood waters. Preferably it should not be located in the flood plain because of the possible damage during floods and because the gage would not be accessible during high water. The gage should not be on an unstable bank or one that might become unstable due to erosion.

The gage should be located on a straight reach of stream rather than on a bend where there will be scour of one bank and fill on the other. This will eliminate many of the plugged intake problems common to stations on bends.

Obviously, not all the desirable criteria for a gaging station site will be found and some modification of these criteria will have to be made for each selection.

Availability of measuring site

Part 3.1.3

The proposed gaging station reaches should be examined for the availability of measuring sites for the various stages anticipated. One of the aspects of this examination is to be certain there will be a measuring site at low flows where the velocities will be in the range where the current meter can measure them accurately. The suitability of cross sections at bridges for accurate discharge measurements at high stages and the suitability of the bridges themselves as measuring structures should be evaluated. If there are no suitable bridges, a site for a cableway or footbridge should be selected.

Accessibility

Part 3.1.4

Accessibility depends on the availability of:

1. Highways or roads.
2. Observers.

The nearer a gaging station is to adequate roads that are open all year, the easier will be the construction and operation of the station. The time saved and convenience of having a gaging station near good roads should be considered in the final selection.

If an observer will be needed at a gaging station, the site selected should be near a populated area where people of sufficient ability to perform the duties of an observer are available. The necessity of having a station near adequate roads becomes more acute if an observer is needed because very few people are willing to hike great distances to be a gaging station observer.

Economics

Part 3.1.5

Economics in most cases is not the controlling factor in the final decision but it should definitely be given consideration. The two important aspects which should be considered in comparing possible sites are the cost of construction and the cost of operation.

The items to be investigated to determine the approximate cost of construction are:

1. Accessibility of the site to manpower, materials, and equipment.
2. Type of material to be excavated.
3. Need for protection of structure from floods.
4. Need for cableway or artificial control.
5. Type of gage installation.

To make an accurate determination of the cost of construction, some time must be spent during the field reconnaissance to find highwater marks of past floods and to discuss with local residents the height of past floods. This information will be essential in determining the exact location and height of the gaging station and the height and length of the cableway if one is necessary.

Consideration must be given to the type of gage installation to be used when considering the economics of the proposed sites. A decision must be made whether it will be a bank or bridge installation and if it is a bridge installation, whether it will be on a pier or on the abutment, and whether it will be on the upstream or downstream side.

Included in the cost of operation should be the annual cost of obtaining the field data such as the discharge measurements, levels, etc., the cost of the station maintenance, and the cost of computing the daily discharge record.

Once the cost of construction and the cost of operation for each proposed site have been estimated, the economics of the proposed sites can be compared.

Measurement of stage

Part 4.0

The stage of a stream or lake is the height of the water surface above an arbitrary datum. Readings of stage at a gaging station are called gage heights. A record of stream stage may be useful by itself. In addition, it is needed for computing daily mean discharge.

Stage records are also maintained on lakes and reservoirs and at the majority of such sites stage is of primary importance.

Stage records may be obtained by systematic observation, by continuous recordings or by recording extremes only.

Non-recording gages

Part 4.1

One method of obtaining a record of stage is by the systematic observations of a nonrecording gage. The advantages of non-recording gages are low initial cost and ease of installation. The disadvantages are (1) the need for an observer and (2) the lack of accuracy of the estimated continuous stage graph which is sketched through points of observation which are usually too infrequent during periods of rapidly changing stage.

Non-recording gages are still in general use as auxiliary gages at water-stage recorder installations to serve the following purposes:

1. They serve as a reference gage to indicate the water surface elevation in the stream.
2. They serve as a reference gage to indicate the water surface elevation in the stilling well. Gage readings on the stream are compared with reference readings in the well to determine whether stream stage is being obtained in the well.
3. When the intakes are plugged or there is equipment failure, the outside reference gage can be observed daily or more often by a local observer to continue the record of stage during the malfunction.

The types of non-recording gages are:

1. Staff gage.
2. Wire-weight gage.
3. Float-tape gage.
4. Electric-tape gage.
5. Hook gage.

Staff and wire-weight gages are the types usually used at non-recording gaging stations. Any of the five types may be used at a recording station. The latter three types are ordinarily used in stilling wells. Readings are made on staff gages directly whereas with the other four types readings are made by measurement to the water surface from a fixed point.

The staff gage may be either vertical or inclined. The vertical staff gage usually consists of porcelain-enameled iron sections. The sections are usually screwed to a board which is fastened to a suitable support. The vertical staff gage can be used in the stilling well as a reference gage or be used in the stream as an outside gage.

An inclined gage usually consists of heavy timber securely attached to a permanent foundation. The face of the timber is graduated in place with the aid of an engineer's level. Various sizes of copper barrel-hoop staples and bronze numerals are usually used for the graduations. The inclined gages are used as outside reference gages.

The wire-weight gage used by the USGS is called the type A gage. This consists of a drum wound with a single layer of cable, a bronze weight attached to the end of the cable, a graduated disk, and a Veeder counter, all within a cast-aluminum box. The disk is graduated in tenths and hundredths of a foot and is permanently connected to the counter and to the shaft of the drum. The cable is made of 0.045 inch diameter stainless-steel wire, and is guided to its position on the drum by means of a threading sheave. The reel is equipped with a pawl and ratchet for holding the weight at any desired elevation. The diameter of the drum of the reel is such that each complete turn represents a 1-foot movement of the weight. A horizontal checking bar is mounted at the lower edge of the instrument in such a manner that when it is moved to the forward position the bottom of the weight will rest on it. The gage is set so that when the bottom of the weight is at the water surface, the gage height will be indicated by the combined readings of the counter and the graduated disk. The type A wire-weight gage is generally used as an outside reference gage.

The float-tape gage is used chiefly as an inside reference gage for a water stage recorder and consists of a float attached to a counter-weight by means of a stainless steel tape. The tape is graduated in the English or Metric system and passes over a float pulley. The float pulley consists of a wheel usually 6 inches in diameter, grooved on the circumference to accommodate the tape and mounted in a standard. An arm extends from the standard to a point slightly beyond the tape to carry an adjustable index. The tape is connected to the float by means of a clamp which also may be used for making adjustments to the tape reading too large to be accommodated by the adjustable index. A 10-inch copper float and a 2-pound lead counter-weight are usually used.

The electric tape gage, like the float gage, is used almost exclusively as an inside reference gage for water-stage recorders. It offers two advantages over float gages: it can be used in a stilling well which is too small to accommodate two floats, and the possibility of errors caused by leaky floats or by the passage of the float line from one side to the other of the float pulley is eliminated. This type of gage consists of a stainless steel tape, graduated in the English or Metric system, to which is fastened a cylindrical weight, a reel for the tape, a source of electric current, and an electric indicating device. All of these parts are supported by an insulated bracket. The electric tape gage developed by the USGS has capacity for tapes in lengths of 25, 50 and 100 feet. The electric indicating device consists of a light sensitive volt meter. The source of electric current commonly used is supplied by a 4.5-volt dry-cell battery, one terminal of which is attached to a ground connection, the other one to a volt meter. The other terminal of the volt meter is connected through the frame, reel, and tape to the weight. The reel is provided with a ratchet arrangement to hold the weight at any desired height. The weight is hollowed to permit the insertion of two loose-fitting half-round bars used in connecting the tape to the weight. After inserting the tape between the flat surfaces of the half-round bars, an Allen head set screw is used to press the bars together to hold the tape in space. Adjustments for the over-all length are made by varying the amount of tape included between the half-round bars. With the gage properly set to correct datum, the weight is lowered until it contacts the water surface, which completes the electric circuit and produces a deflection in the needle of the voltmeter. With the weight held in the position of contact, the tape reading is observed at the index provided on the reel mounting. In order to prevent errors in the readings because of water collecting on the bottom of the weight, the bottom of the weight is concave so that only the edge on the circumference of the weight contacts the water surface.

The hook gage is an inside reference gage and consists of a movable staff graduated in feet or meters and placed so that the graduations read downward from the top to the bottom of the staff. The staff has a steel hook at the bottom and is arranged to slide against a 1-foot or 1-meter level-rod scale which is screwed to a base. The height of the water surface is determined by drawing the point of the hook to the surface of the water and, with the staff in that position, observing the foot or meter mark on the movable staff and the fractional part of a foot or meter on the fixed scale which is in juxtaposition therewith. The steel hook should be either plated or made of stainless steel to prevent rust and corrosion.

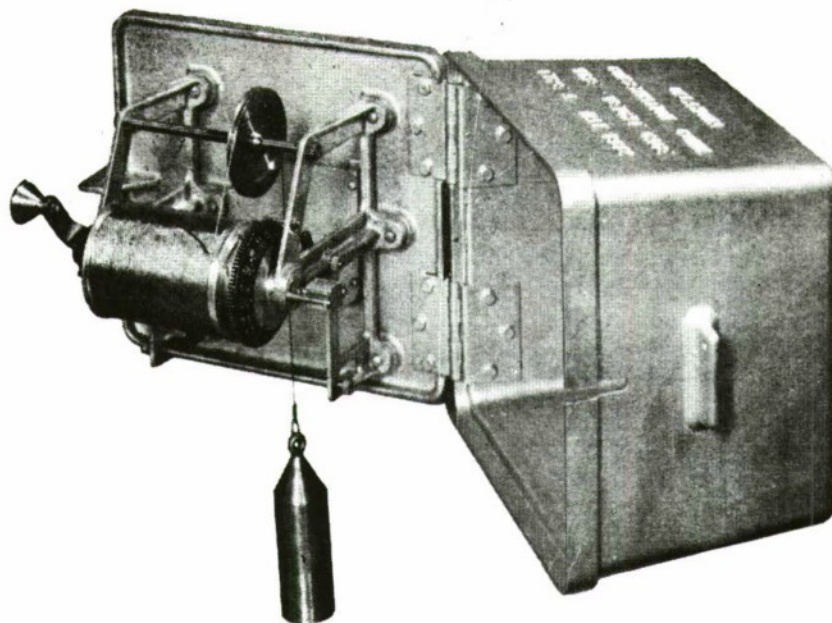


Figure 9.--Type A wire weight gage.



Figure 10.--Float tape gage.

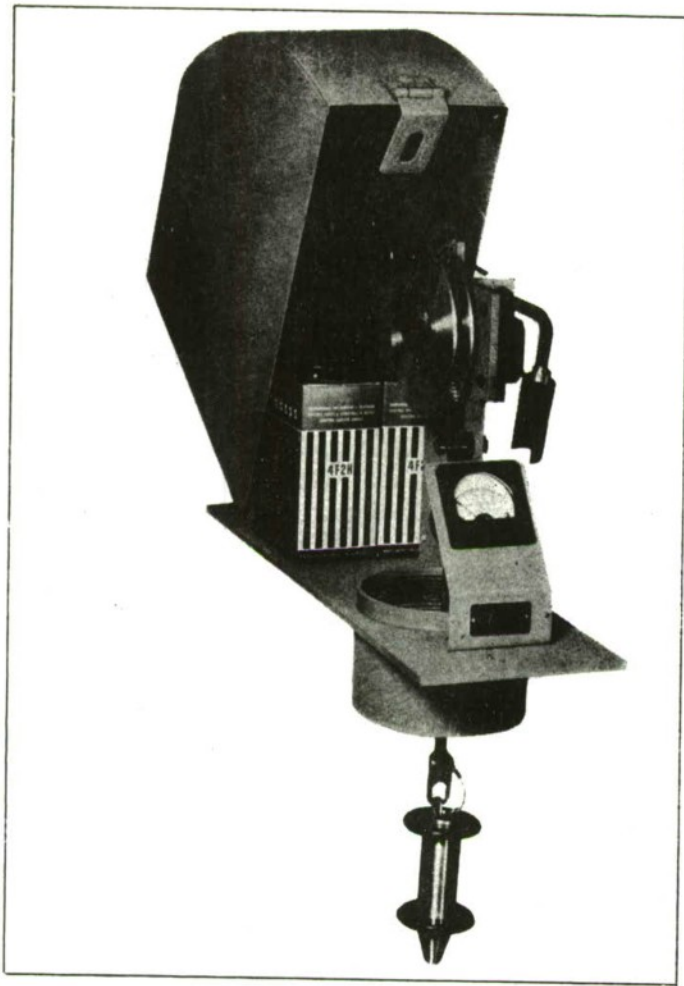


Figure 11.--Electric tape gage.

Figure 12. Hook gage.



A water-stage recorder is an instrument for producing a graphic record of the rise and fall of a water surface with respect to time. It consists of a time element and a gage-height element which, when operating together, produce on a chart a record of the fluctuations of the water surface. The time element is controlled by a clock which may be spring, weight, or electrically driven. The gage-height element is actuated by a float.

Float actuation is essentially the same as for the non-recording float-tape gage described in part 4.1 except that the float pulley is attached to the water-stage recorder. The float and counterweight are usually suspended from a perforated steel tape but plain or beaded cable also may be used. Spines on the circumference of the float-tape pulley match perforations in the tape. As the float rises or falls the float pulley turns a proportional amount thereby changing the gage height reading on the recorder. A copper float 10-inches in diameter is usually used, but smaller and larger sizes are used depending on the type of recorder, gage height scale, and accuracy requirements.

Graphic recorder

Part 4.2.1

The graphic recorder supplies a continuous trace of water stage with respect to time on a chart. Generally the gage height element moves the pen or pencil stylus and the time element moves the chart, but in some recorders this is reversed. The range of available gage height scales is from 1 meter = 1 meter to 1 meter = 50 meters, and the range of available time scales is from 0.3-inches per day to 9.6-inches per day. Normally the 1 meter = 5 meters or the 1 meter = 10 meters gage height scale is used and the 1.2- or 2.4-inches per day time scales are used.

Most graphic recorders are capable of recording an unlimited range in stage either by use of reversing devices on the strip-chart types or by unlimited revolutions of the drum types.

Most strip-chart recorders will operate for several months without servicing; drum-type recorders require attention at weekly or monthly intervals.

Accuracy and sources of error

Part 4.5

The degree of accuracy needed for the discharge record will determine to a great extent the refinement needed for the stage records. For most stream gaging stations gage heights to the nearest centimeter

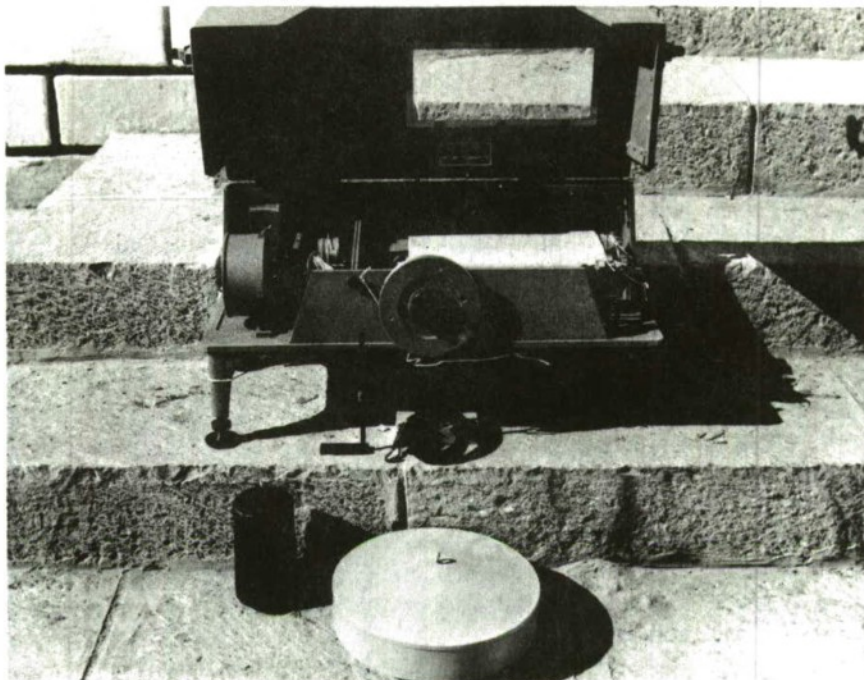


Figure 13.--Graphic water stage recorder.

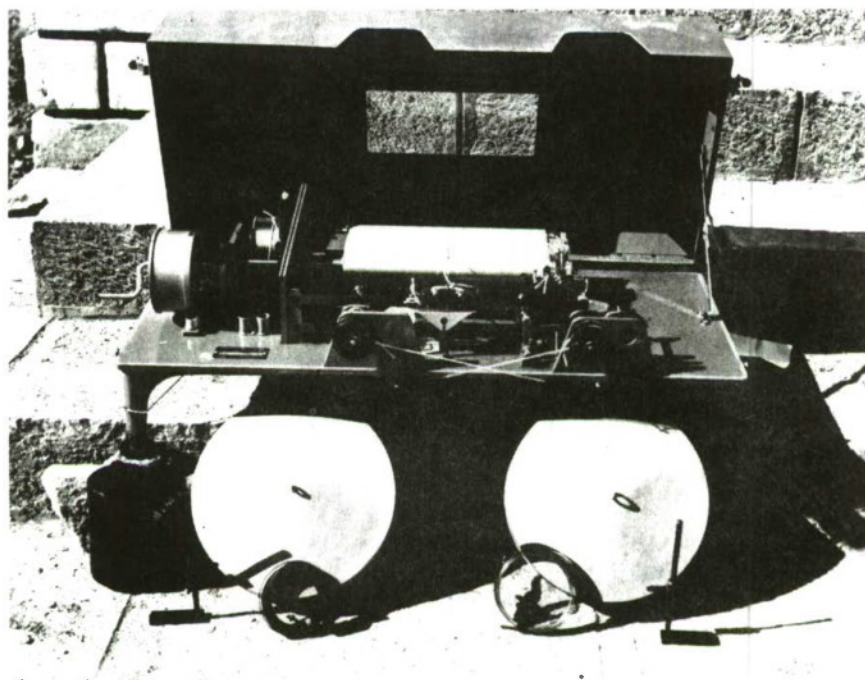


Figure 14.--Duplex graphic water stage recorder.

are of sufficient accuracy. There are certain special cases involving small streams and low flows where greater refinement is required.

The sources of error for non-recording gages are concerned mainly with the observer. The record can only be as good as the observer. It is important when selecting an observer that a reliable, intelligent person be chosen. If the observer is careless in his duties the gage height record can't help but be of poor quality. Normally it is not too difficult to find a reliable observer if the gage site has been conveniently located.

The observer should be adequately trained. One of the easiest ways to teach an observer to read a gage is to explain meters and centimeters in terms of Afghanis and Puls. The importance of being close to the staff gage and close to the water surface when reading the gage should be stressed.

The frequency of gage readings for non-recording gages will be an important factor in the accuracy of the continuous record synthesized from these readings. Normally the gage should be read twice a day with additional readings during periods of rapidly changing stage. Once daily readings may be sufficient during periods of low flow and for some reservoir or lake gages.

The hydrographer should visit the observer when possible and add his reading in the observer's gage height book. This serves as a check on the observer's recent readings and will indicate to the observer the importance of his work.

The sources of error for recording gages are numerous but they can be kept to a minimum if the hydrographer performs his duties properly. Recorders equipped with floats, float cables, and counterweights necessarily contain some friction and lost motion which result in a slight lag in the recording of changes in gage height. If the recorder is cleaned and oiled periodically this lag and friction can be kept to a minimum. The amount of this lag will depend on the resistance of certain parts of the instrument to motion, and on the original setting of the index or stylus relative to rising or falling stages. With every change of stage a portion of the float line passes from the rising to the falling side of the float pulley, thus introducing a shift in weight equivalent to twice the weight of the transposed line. This shift in weight will tend to cause a change in the depth of submergence of the float and therefore the recorded gage height will be correspondingly in error. If the stage rises until the counterweight and a portion of the line become submerged, the indicated height will be in error by an amount proportional to the water displaced by the line and weight. The error due to the submergence of the line and

weight tends to compensate the error produced by the line shift. It follows, therefore, that by using a float of large diameter, reducing the instrumental friction, using light float lines and counterweights that are not too heavy; errors due to the lag, line shift, and submergence of the weight and float line may be reduced to a negligible amount. A further source of error is due to the tendency of the recorder charts to expand and contract with changes in temperature and humidity, and to improper alinement of the paper on the instrument; or, if the chart paper is contained on a roll, the graduations of the paper possibly may not be accurately spaced with respect to the margins.

If the clock is not adjusted properly errors will be introduced because the pen or pencil will not be at the correct time. Low temperatures and lack of cleaning and oiling of the clock are usually the causes of improper clock operation. This problem can be helped by adding extra weight to the clock weight during cold periods and by periodic cleaning and oiling of the clocks by an expert.

Another possible source of error is the movement of the reference gages due to frost action or settling. This error can be reduced by periodic checking of the reference gages by levels. Oil leaking from the oil tube into the well is another source of error. This error can be reduced by checking to see if there is oil in the well at the time of each inspection. This can be done by placing a glass tube of small diameter in the water so that one end is in the water and the other is above the water surface. Next the hydrographer places his finger over the end of the tube above the water surface and then raises the tube out of the water. Then the hydrographer can tell by looking at the liquid in the tube if there is any oil on the water surface. If there is he should measure the depth of oil. The oil can be removed by skimming it off the top with a bucket or by pumping the well out and then pumping fresh water in.

Carelessness on the part of the people servicing water-stage recorders constitutes the greatest possible source of error. Incorrect gage readings, inaccurate setting of pens or dials, failure to wind the clock, failure to be certain the clock was operating after being wound, failure to check and replace weak batteries, failure to put the pen back on the chart, leaving the pen in the improper reversal, failure to tighten the set screws used for adjusting the pen gage height reading, failure to see that the intake is open, failure to clean and oil the recorder at least annually, failure to use the proper grade of oil, are some of the things that frequently cause errors in gage height records or loss of record.

Most of the sources of error in gage height records can be eliminated by more careful attention to details and by following the manufacturer's instructions for the various recording devices.

Measurement of discharge

Part 5.0

The discharge of a stream is the quantity of water flowing past a cross section of the stream in a unit of time. Stream discharge is normally expressed in cubic feet per second (cfs) or cubic meters per second (m^3/sec).

The most common methods of determining discharge in open channels are by means of:

1. Current meters.
2. Weirs.
3. Parshall flumes.
4. Tracer methods.
5. Volumetric methods.
6. Floats.
7. Indirect measurements based on surveys of channel dimensions and water-surface slope.

The current meter, float, some of the tracer, and some of the indirect measurement methods of determining discharge require separate determinations of velocity and area. In others, discharge is obtained without determining either velocity or area directly.

Current-meter measurements

Part 5.1

Most discharge measurements of streamflow and of flow in large artificial channels are made by the current-meter method because it is adaptable to a wide range of velocities and is practically unlimited as to the total discharge which can be measured. Essentially, the method consists of: (1) measuring the velocity of flow in and the area of each of several parts of a cross section, (2) computing the discharge in each part as the product of the velocity and area, and (3) summing the partial discharges to obtain the total.

The usual method of making a discharge measurement is explained by reference to figure 16 which shows a cross section of a channel. The depth of water is measured by sounding line or rod at Locations 1, 2, 3, 4, and so forth. The velocity of the water is measured by current meter at each of these locations at such position or positions in the vertical that the mean velocity in the vertical is obtained. The methods of sounding and of positioning the current meter are described in another section of this training course. The discharge past a partial section is computed by:

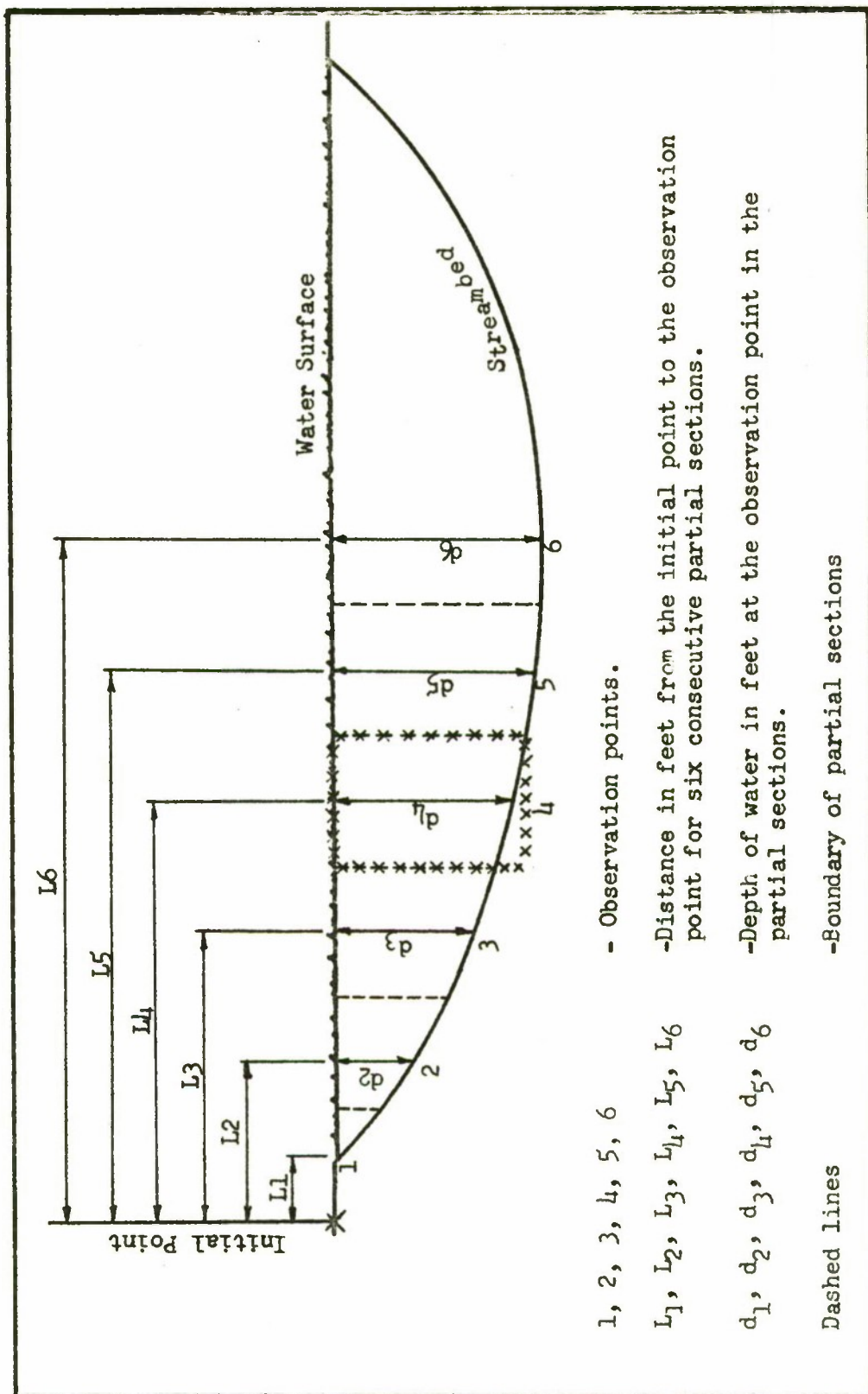


Figure 15.-Mid-section method of computing discharge measurements.

$$q_4 = v_4 \left[\frac{(L_4 - L_3) + (L_5 - L_4)}{2} \right] d_4 = v_4 \left[\frac{L_5 - L_3}{2} \right] d_4$$

in which q_4 = discharge in cubic feet per second through partial section 4 (see fig. 16).

v_4 = mean velocity in feet per second in the vertical at location 4.

L_3, L_4, L_5 = distances in feet from the initial point to locations 3, 4, and 5 respectively (see fig. 16).

d_4 = depth of water in feet at location 4 (see fig. 16).

(Note: Either the English system or the Metric system of measurement can be used providing the units used are consistent.)

The area which is defined by this formula is that shown by the X line around location 4 in figure 16.

The formula for partial section 1 at the end of the cross section is:

$$q_1 = v_1 \left[\frac{L_2 - L_1}{2} \right] d_1$$

For the case shown in figure 16, q_1 would be zero because the depth and therefore the velocity at observation point 1 is zero. However, when the cross section boundary is a vertical line at the edge of the water, the depth is not zero and velocity at the end section may or may not be zero. The formula shown for q_1 is used whenever there is water only on one side of the observation point such as at piers, abutments, and islands. It is usually necessary to estimate the velocity at end sections as some percentage of the preceding or subsequent section because it is normally impossible to measure the velocity accurately for the current meter will be affected by nearness to a boundary, and there is also the possibility of damage to the equipment if the flow is turbulent.

The summation of the discharges for all the partial sections is the total discharge of the stream. This method of computation is called the mid-section method, and some of the elements of this current-meter measurement will be explained in detail in a later section.

Current-meter measurements are classified into five types, depending on the method the hydrographer uses to cross the stream. The five types are:

1. Wading.
2. Cableway.
3. Bridge.
4. Boat.
5. Ice.

Instruments and equipment

Part 5.1.1

Current meters, timers, and counting equipment are used with all five types of measurements. The other equipment used depends on the type of measurement being made. Instruments and equipment are described under the following categories in this section:

1. Current meters.
2. Sounding equipment.
3. Width-measuring equipment.
4. Equipment assemblies.
5. Miscellaneous equipment

Current meters

Part 5.1.1.A

A current meter is an instrument used to measure the velocity of flowing water. The principle of operation is based on the proportionality between the velocity of the water that strikes it and the rate of rotation of the rotor of the meter. By placing a current meter at a point in a stream and counting the number of revolutions of the rotor in a known interval of time, the velocity of water at that point can be determined from the calibration of the meter.

The number of revolutions of the rotor of the meter is obtained by counting the number of clicks in an earphone or by observing the number of contacts on an electric counter. The earphone or counter is in an electrical circuit which is closed twice each revolution, once each revolution, or once each fifth revolution of the rotor by contact points in the meter head. Each closure produces a click in the earphone or registers a count on the electric counter.

The time interval during which the revolutions are being counted is determined by use of a stop watch.

Modern current meters are divided into two main types:

1. Cup or vane type meters with the axis of rotation vertical.
2. Vane or propeller type meters with the axis of rotation parallel to the direction of flow.

The vertical axis meters have the following characteristics:

1. They will operate at lower velocities than the horizontal axis meters.
2. The bearings are well protected from silty water.
3. The rotor may be repaired in the field without adversely affecting the calibration.
4. A single rotor serves the entire range of velocities.

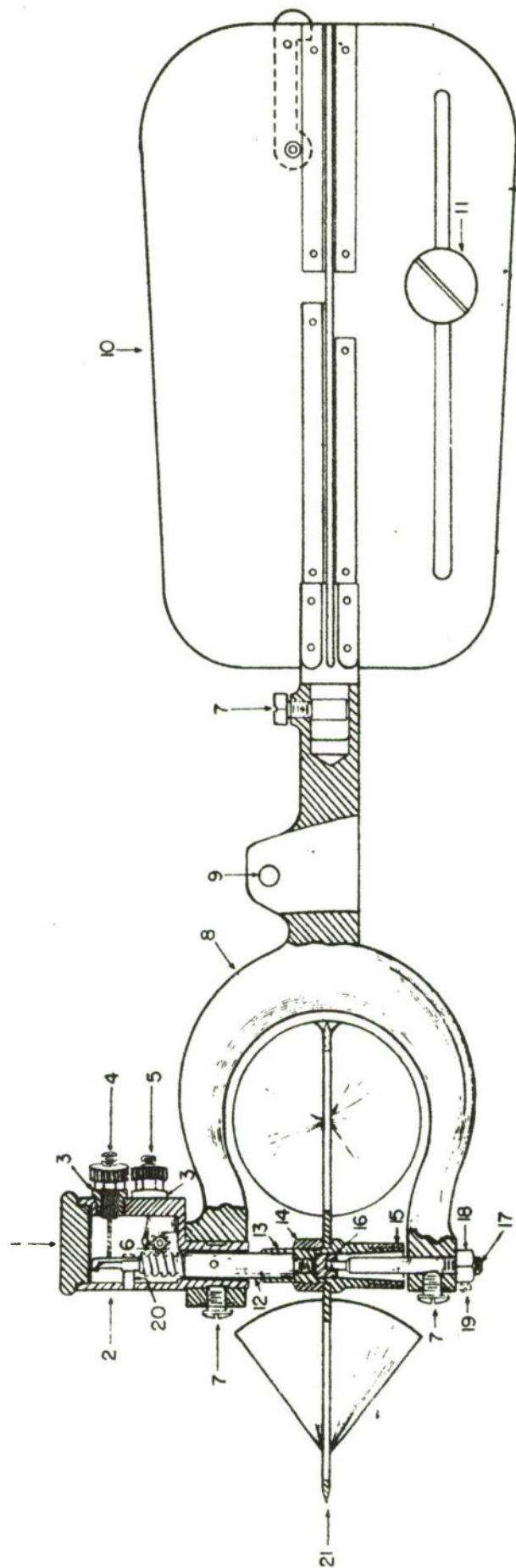
The horizontal axis meters have the following characteristics:

1. Because of axial symmetry of flow, the blade rotors cause smaller disturbances than cup rotors.
2. The forces acting on the rotor do not cause bending moments in the rotor spindle which reduces the bearing friction.
3. The blade rotors are less sensitive to fouling by foreign bodies carried by the stream than are cup rotors.

The U. S. Geological Survey uses a vertical axis type of current meter called the small Price meter. The latest type of Price meter is called the type AA meter. This meter differs from the Price type A meter only in the construction of the pivot and pivot bearing.

In addition to the type AA meters, the USGS uses a Price meter called the pygmy meter in shallow depths. It is similar to the type AA meter but differs in being only two-fifths as large, having no tail piece, and having a different type of contact chamber. The pygmy meter makes electrical contact each revolution and is used only for rod suspension.

The USGS has recently developed a four-vane vertical axis meter. This meter is useful for measurements under ice cover because the vanes do not fill up with slush ice, and for measurements from boats because it



EXPLANATION

- | | | | |
|----|---|----|--------------------------------------|
| 1 | Cop for contact chamber | 11 | Balance weight |
| 2 | Contact chamber | 12 | Shaft |
| 3 | Insulating bushing for contact binding post | 13 | Bucket-wheel hub |
| 4 | Single-contact binding post | 14 | Bucket-wheel hub nut |
| 5 | Penta-contact binding post | 15 | Raising nut |
| 6 | Penta gear | 16 | Pivot bearing |
| 7 | Set screws | 17 | Pivot |
| 8 | Yoke | 18 | Pivot adjusting nut |
| 9 | Hole for longer screw | 19 | Keeper screw for pivot adjusting nut |
| 10 | Toilpiece | 20 | Bearing lug |
| | | 21 | Bucket wheel |

Figure 16.--Type AA Small Price current meter.

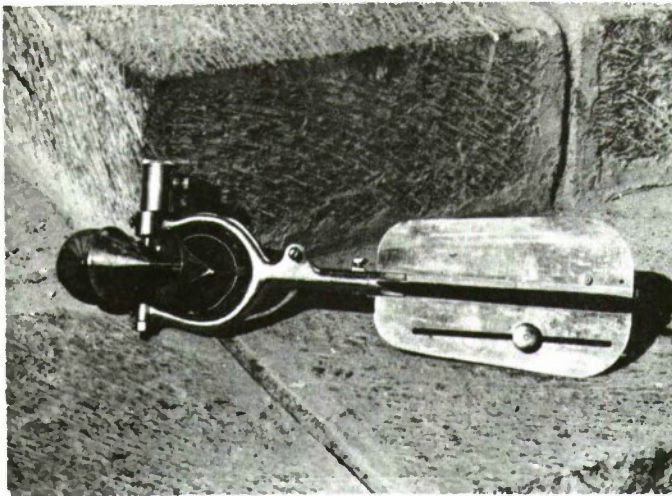


Figure 17.--Small Price current meter.

Figure 18.--Small Price current meter disassembled.

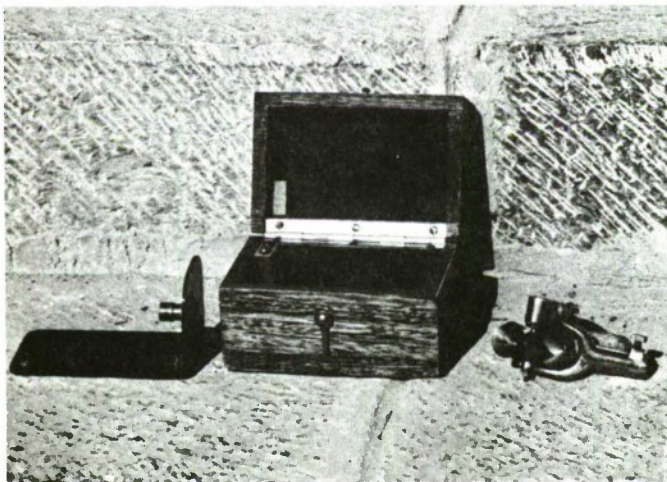
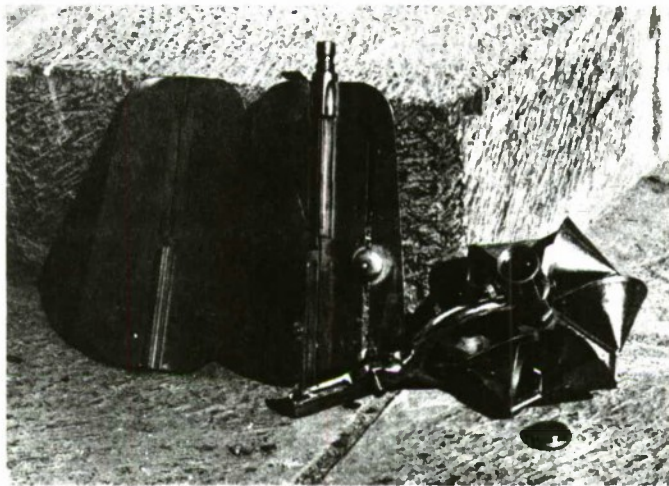


Figure 19.--Pygmy current meter.

will not measure the vertical component of velocity. The yoke of the vane meter is made so it will fit in holes made in the ice by an ice auger or is made so that the meter can be used for cable suspension. The vane meter has the disadvantage that it does not rate as well as the Price type AA meter at velocities below 0.5-foot per second.

A new contact chamber has recently been designed by the USGS for the type AA and vane type meters which eliminates the standard wiper or "cat's whisker" contact. The "cat's whisker" contact is the bronze wire with the bead of solder on one end that strikes the eccentric of the meter shaft to complete the electric circuit and produce a click in the earphone. There was a need for a new contact chamber because of:

1. Difficulties with the wiper contact when operating in water of high salt concentration.
2. The problem of frequent adjustments of the wiper contact.
3. The dragging at low velocities of the wiper contact made the use of automatic electric counters impossible because several signals were sent to the counter for each revolution.

The new contact chamber contains a specially developed magnetic switch, glass enclosed in a hydrogen atmosphere and hermetically sealed. The switch assembly is rigidly fixed in the top of the meter head just above the tip of the shaft. The switch is operated by a small permanent magnet placed slightly off center and rigidly fastened to the shaft. The switch, in any revolution, quickly closes when the magnet is just beneath it, and then promptly opens when the magnet moves away. The magnet is properly balanced on the shaft.

All type AA meters can be converted to the magnetic switch type by replacing the shaft and the contact chamber. The new contact chamber with the magnetic switch has no removable cap on it for there is no need to open the chamber. The magnetic switch is placed in the contact chamber through the tapped hole for the binding post. The rating of the meter is not altered by the change.

An automatic electric counter which should be used with the magnetic switch contact chamber is described in part 5.1.1.E.2. The automatic counter should be used with the magnetic switch contact chamber because the earphone would hear four clicks per revolution and a suitable diode is necessary in the circuit when an earphone is used.

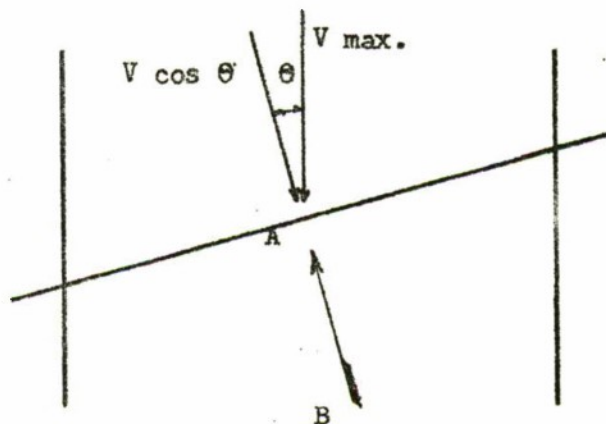
The care and rating of the vertical axis meters will be described in detail in part 5.1.1.A.2.

There are several types of horizontal axis meters in use:

1. Ott.
2. Neyrpic.
3. Haskell.
4. Hoff.

The Ott meter is made in Germany, the Neyrpic meter is made in France and these two meters are extensively used in Europe whereas the Haskell and Hoff meters were developed in the USA and are still used to a limited extent there.

The Ott meter is a precision made instrument but is not used extensively in the United States because of its limitations for general purpose use and because it is not as durable as the Price meter under extreme conditions. The makers of the Ott meter have developed a component propeller which in oblique currents automatically registers the velocity projection at right angles to the measuring section for angles up to 45 degrees. For example if this component propeller were held in the position AB in the sketch below it would register $V \cos \theta$ rather than $V \max.$ as the Price meter would.



The Neyrpic meter is used in France but only rarely in the USA because it has the same disadvantages as the Ott meter.

The Haskell meter has been used by the USGS in streams that are deep, swift, and clear. By using propellers with different pitches of screw, it may be used for a considerable range of velocity. It is a durable meter but has most of the other disadvantages of horizontal axis meters.

The Hoff meter is used by the USGS in investigational work. The propeller is light in weight, consisting of three or four vanes of hard rubber. Due to the lightness of the propeller, it is reported to be adapted to the measurement of low velocities but it is not suited for rugged use.

The USGS in cooperation with the California Department of Water Resources is developing an optical current meter. This meter is a stroboscopic device designed to measure surface velocities in open channels without immersing equipment in the stream. The optical current meter will find its principal use in measurements of discharge under conditions that cannot be accommodated by conventional stream gaging equipment.

Care and rating of Price current meters

Part 5.1.1.A.2

The hydrographer should examine the current meter before and after each discharge measurement with regard to the following details to make sure it is in good condition:

1. The vanes or cups of the rotor should be inspected for damage.
2. The pivot and bearing should be inspected for wear or damage.
3. The shaft should be straight. By spinning the rotor slowly, and watching the metal frame to which the cups or vanes are fastened, eccentricity in the rotor and hub assembly may be readily detected. The shaft may be bent by (1) a sharp blow, (2) raising the rotor too forcibly, and (3) by unscrewing the contact chamber cap when the rotor and hub assembly are in the raised position.

The following items should be checked before a discharge measurement is begun:

1. When supported by the hanger screw the meter should balance freely and come to rest in a horizontal position.
2. When supported on a rod the axis of the rotor should be parallel to the rod.
3. The conductor wire attached to the binding post should not interfere with the balancing of the meter or the spinning of the rotor.

Current meters should be cleaned and oiled at least daily when in use. When measurements are made in silty water it is desirable to clean and oil the meter after each measurement.

The Price current meter has the following bearing surfaces which need cleaning and oiling each time the meter is used:

1. The pivot bearing.
2. The bearing surfaces between the penta gear and the acme threads on the shaft.
3. The cylindrical bearing of the small shaft of the penta gear.
4. The cylindrical bearing of the shaft within the bearing lub.
5. The thrust bearing between the shaft and the cap.

The pivot is the part of the meter that needs replacement most often. After being used, the pivot should be examined with a magnifying glass to see whether the point is fractured, rough, or worn flat at the apex. See table 1 for the procedure to follow for the adjustment of pivots.

Table 1.--Adjustment of current meter pivots

Sequence	Operation
1	Make sure that the meter has been properly oiled, then hold meter in inverted position with pivot uppermost.
2	Release keeper screw for pivot adjusting nut and unscrew the nut a few turns.
3	Release set screw and advance pivot until all vertical play of the hub assembly is eliminated.
4	Tighten set screw temporarily, and advance pivot adjustment nut until it touches the yoke.
5	Release set screw (not too far because the pivot should not revolve), and advance the pivot adjusting nut one-fourth turn. Then tighten keeper screw.

Sequence	Operation
6	Push the pivot inward as far as it will go, and tighten set screw.

Note.--The adjustment of the pivot for the vane type meter is identical to the above procedure except that in step 5 the pivot adjusting nut is advanced one-sixth turn rather than one-fourth turn. Also the pivots for the vane meter do not have a keeper screw in the pivot adjusting nut - instead a lock nut is used to replace the pivot adjusting nut and set screw.

No current meter should be transported with the pivot bearing resting on the pivot. The pivot and pivot bearing should be separated by the raising nut if provided. For pygmy meters the pivot should be removed and replaced by a brass plug when the meter is not in use.

Spin tests

The spin test is an easy method of determining the condition of the current meter. In making this test, the meter should be so placed that the shaft is in a vertical position and the rotor protected from air currents. The rotor is then given a quick turn by hand to start it spinning, and the duration of its spin is timed with a stop watch. As the rotating rotor nears the stopping point, its motion should be carefully observed to see whether the stop is abrupt or gradual.

Regardless of the duration of the spin, if the rotor comes to an abrupt stop, the cause of such behavior should be found and corrected before the meter is used. In such instances, a lack of oil, the maladjustment of the penta gear, and a misalignment of the yoke are possible sources of trouble that should be checked.

Table 2 shows the duration of spin that may be expected of various types of meters.

Table 2.--Duration of spin tests

Type of meter	Normal spin of new (or newly reconditioned) meters	Minimum permissible value in field operations
Type AA (Low velocity meters)	4 1/2 to 5 minutes	2 1/2 minutes
Type A Type AA (General duty meters)	4 minutes	1 1/2 minutes
Vane meters	3 minutes	1 1/2 minutes
Pygmy meters	1 1/2 minutes	1/2 minute

Note: The "minimum permissible value" shown in this table applies only if the rotor comes to a smooth, gradual stop.

Repairs to current meters

Many minor repairs to current meters can be made in the field, but whenever a meter is damaged so that the bearings are out of alinement, the tail vanes and the rotor are not properly alined, or the rotor is distorted beyond repair in the field, the meter should be transmitted to the USGS for reconditioning.

Rating of current meters

In order to determine the velocity of the water from the revolutions of the rotor of a current meter, a relation must be established between the angular speed of the rotor and the velocity of the water which causes it to turn. The establishment of the relation, known as "rating the current meter", is done for the USGS by the National Bureau of Standards. Individual meters differ in their ratings principally because of slight variations in each individual rotor. Different sizes or shapes of weights suspended below the meter effect the rating as do variations in the distance between the meter and weight. Because of these effects upon the ratings, each meter used

by the USGS is rated individually for at least one suspension, generally the rod suspension, and coefficients based on the analysis of many comparative ratings are applied to the rod suspension rating to obtain ratings for other suspensions (see table 3). However, when current meters are used under conditions that require exceptional accuracy, they are rated with the identical suspensions to be used for the discharge measurements.

The current-meter rating station operated by the National Bureau of Standards in Washington, D.C., consists of a sheltered reinforced concrete basin 400-feet long, 6-feet wide and 6-feet deep. Atop the vertical walls of the basin, and extending its entire length are steel rails that carry an electrically driven rating car. This car is operated to move the current meter at a constant rate of travel through the still water in the basin. Although the rate of travel can be accurately adjusted by means of a hydraulic regulating gear, the average velocity of the moving car is determined for each run by making an independent measurement of the distance it travels during the time that the revolutions of the rotor are electrically counted. A scale graduated in feet and tenths is used for this purpose. Eight pairs of runs are usually made in the rating of each current meter. A pair of runs consists of two traverses of the basin, one in each direction, at approximately the same speed. Practical considerations usually limit the ratings to velocities ranging from one-tenth of a foot per second to about 15-feet per second, although the rating car can be operated at both lower and higher speeds. Unless a special request is made for a more extensive rating, the lowest velocity used in the rating is about 0.2-foot per second, and the highest is about 8.0-foot per second.

Table 3.--Coefficients for converting rod suspension ratings to ratings with Columbus type weights.

Suspension	Velocity	Coefficient
15 C .5'	0.25	1.01
	.5-2.9	.99
	3.0-up	.995
30 C .5'	.25	1.020
	.5-up	1.005

Suspension	Velocity	Coefficient
50 C .55'	.5	1.005
(Meter at hole of C-type	1.0-4.9	.995
hanger marked "15")	5.0-up	1.00
50 C .9'		
75 C 1.0'	.5-up	1.00
100 C 1.0'		
150 C 1.0'	.5-up	.995
200 C 1.5'	1.0	.995
	2.0-up	1.005
300 C 1.5'	1.0	.99
	1.7-3.6	.995
	3.7-up	1.00

Note.--Suspension distances are from horizontal axis of current meter to bottom of weight. Coefficient for velocities not shown may be obtained by interpolation.

CURRENT METER RATING TABLES

For convenience in field use, the data from the current meter ratings are reproduced in tables. The velocities corresponding to a range of 3 to 350 revolutions of the rotor within a period of 40 to 70 seconds are listed in the tables. This range in revolution and time has been found to cover general field requirements. To provide the necessary information for extending a table for the few instances where extensions are required, the equations of the rating table are shown in the spaces provided in the heading.

It should be noted that the equations given are those of the rating table, and not necessarily those of the actual rating. If a rating table already on file matches a rating within certain tolerances, that table is selected in preference to preparing a new one. Those tolerances are listed on the next page.

Revolutions of bucket
wheel per second

Tolerances in percent

0.1

1.0

1.0 and above

0.5

After "limits of actual rating" in the heading of the current meter rating table is shown the velocities at which the slowest and fastest runs were made in the rating flume. Other information furnished consists of the type and number of the current meter, the method of current-meter suspension to which the table applies, the date of its rating, and the index number of the rating table.

Sounding equipment

Part 5.1.1.B

Sounding is commonly done mechanically, the equipment used depending on the type of measurement being made. Depth and position in the vertical are measured by use of a rigid rod or by use of a sounding weight suspended on a cable. The cable is controlled either by a reel or by a handline. A sonic counter is also available, but it is usually used with a reel and a sounding weight.

Sounding equipment is described in the following categories:

1. Wading rods and ice rods.
2. Sounding weights.
3. Sounding reels.
4. Handlines.

Wading rods and ice rods

Part 5.1.1.B.1

There are two basic types of wading rods in use in the Geological Survey, the round rod and the top-setting rod. The round rod is also used for making discharge measurements through ice cover, and has the advantage that it can be taken down to 1-foot lengths for back packing. The top setting rod is relatively new but is gradually replacing the round rod in many places because of the convenience in setting the meter and also because the hydrographer can keep his hands dry in cold weather when using this rod.



Figure 20.--Round wading rod assembly.

The round wading rod consists of the following parts:

- 1 base plate
- 1 lower section
- 3 or 4 intermediate sections
- 1 sliding support
- 1 pole end (not essential)

The round rod sections are made of 1/2 inch diameter nickel-plated brass tubing, 1-foot long. The rod is graduated at intervals of 0.1-foot. The graduations consist of single circumferential grooves every 0.1-foot, double grooves at the half-foot, and quadruple grooves at the foot graduations. The rod is placed in the stream so that the base plate rests on the stream bed and the depth of water can be read on the graduated rod.

The sliding support consists of a one-piece nickel-plated bronze casting drilled to accommodate the rod. The meter is mounted on the sliding support and is set at the desired position on the rod by sliding the support on the rod. The sliding support is held at the desired position on the rod by means of a spring-held brass screw which impinges against the rod. The distance from the top of the sliding support to the center line of the meter is exactly 0.1-foot which makes it easy to set the meter properly on the rod by setting the top of the sliding support 0.1-foot above the position desired for the center line of the meter. The meter can also be set at the proper position by setting the indented slot of the sliding support at the position desired.

The ice rod consists of as many intermediate sections of round rod screwed together as it takes to give the desired length. About three feet longer than the maximum depth of the water to be encountered in a cross section is the most convenient length for an ice rod. About 10-feet to 12-feet is the maximum practical length for an ice rod; depths greater than 10 feet are usually measured with a sounding weight and reel. The base plate, sliding support, and lower section are not used on an ice rod. Instead, a special lower section is used which screws directly into the top of the contact chamber of the vane type ice meter. If a Price meter is used under ice cover another type special lower section can be used which holds the meter by means of the hanger screw. All lower sections for ice rods are made now so that the center of the vanes or cups is at the 0-foot point on the rod.

The top-setting wading rod assembly consists of a 1/2-inch hexagonal main rod for measuring depth and a 3/8-inch diameter round rod for setting the position of the current meter. The main rod is graduated in the same manner as the round wading rod except that the foot marks are triple grooves rather than the quadruple grooves. The setting rod is marked with foot graduations only (actually 0.4-foot apart) and the tenths of a foot scale is marked on the handle.

The setting scale is for the 0.6-depth method (see part 5.1.2.C). By adjusting the setting rod to read the depth of water, the meter is automatically positioned for the 0.6-depth method. The 0.6-depth setting might also be described as the 0.4-depth position up from the streambed. If the actual sounding were divided by 2 before making the setting and setting this new value - the meter would be located at the 0.2-depth position up from the streambed. If the actual sounding were multiplied by 2 and this value used to make the setting the meter would be at the 0.8-depth position up from the streambed. These two positions represent the conventional 0.2 - and 0.8-depth positions, but in reverse, and this is the method used to set the meter for the 0.2- and 0.8-depth positions (see part 5.1.2.B).

The top-setting wading rod is now designed so that two penlite flashlight batteries may be placed in the handle. A plug spring assembly and contact assembly may be purchased from the USGS to adapt the rod to this type setup, and thereby eliminate the need for a battery in the circuit wire from the rod to the earphone.

Sounding weights and accessories

Part 5.1.1.8.2

When a stream is too deep or too swift to wade, it becomes necessary to suspend the current meter in the water from a boat, bridge, or cableway. In order for the current meter to remain stationary in the water a sounding weight is suspended below it. The weight also prevents damage to the meter when the assembly is lowered to the streambed to determine the depth of water.

The type of sounding weight now used is the Columbus type weight, commonly called the C-type. They are made in sizes of 15, 30, 50, 75, 100, 150, 200, and 300 pounds. Some weights heavier than 300 pounds have been made for special purposes. The 15-pound weight is a one-piece casting of gun-metal bronze. All the other sizes are cast of antimonial lead and contain removable aluminum alloy tail vanes attached to structural aluminum angles that are cast into the weight. The vanes position the weight parallel to the current and can be removed for straightening or replacement. The weights are streamlined and offer a minimum of resistance to flowing water. Each weight has a vertical slot in it to accommodate a weight hanger and it also has a horizontal hole drilled through it for the weight hanger pin which secures the weight hanger in the weight. When the current meter is placed on the weight hanger, the nose of the weight extends beyond the cups of the meter and hence affords protection to the cups.



Figure 21.--Sounding weights.

The weight hanger is a stainless steel bar which is attached at the upper end to the connector at the end of the sounding line from a sounding reel or handline. The lower end of the weight hanger is then attached to the sounding weight. The current meter is attached to the hanger between the connector and the weight.

There are three types of weight hangers:

1. The Columbus or C-type, 1/8-in x 3/4-in x 12-in. (for weights up to 150 pounds).
2. Heavy weight type, 1/8-in x 3/4-in x 18-in (for 200 and 300 pound weights).
3. Heavy weight type, 1/8-in x 1 1/2-in x 18-in (for 200 and 300 pound weights which have the slots properly lengthened to accommodate a hanger of 1 1/2-in width).

The Columbus type hanger has three holes in it for the hanger screw of the current meter. The meter hanger screw attaches the yoke of the current meter to the weight hanger. The meter hanger screw is placed through the bottom hole for supporting the meter when a 30-pound sounding weight is used, and then the center of the meter cups is 0.5-foot above the bottom of the weight. This arrangement is designated as 30 C .5, which means that a 30-pound Columbus type weight is being used and the center of the meter cups is 0.5-foot above the bottom of the weight. The hanger screw goes through the middle hole when 15 and 50 pound weights are used. The designations for these arrangements are 15 C .5 and 50 C .55. The hanger screw goes through the upper hole when 50, 75, 100, and 150-pound weights are used. The designations for these arrangements are 50 C .9, 75 C 1.0, 100 C 1.0, and 150 C 1.0. Each of the two heavy weight type hangers has but one hole for the hanger screw of the current meter and the designations for these arrangements are 200 C 1.5 and 300 C 1.5.

In the past some hydrographers have used 75 and 100 pound weights and suspended the meter from the middle hole. This arrangement has been used in swift shallow streams so that more accurate methods of measuring velocity could be used. Recent tests conducted at the National Bureau of Standards indicate that the rating of the meter when so suspended is changed from 2% to 5% from the rating when rod suspended. Therefore, the use of these suspensions is not recommended. Some hydrographers have had a special hole drilled in their weight hangers above the "15" hole for use in suspending the meter when 75 and 100 pound weights are used. The suspension coefficients for this arrangement are close to unity.

Weight hanger pins of various lengths are available for attaching the weight hanger to the sounding weight. The pins are made of stainless steel, threaded on one end to screw into the weight hanger and slotted on the other end to accommodate a screwdriver.

Sounding reels

Part 5.1.1.B.3

There are six basic sounding reels in common use in the USGS at present. Since 1950 there has been almost a complete redesign of all reels except the Canfield. All the larger reels now have two numbers after their letter designation and these numbers indicate the year the reel was redesigned.

The A-pack reel fills the need for a suitable reel to carry to stations located a considerable distance from the highway. Besides being used on cableways, it is also adaptable to use on cranes, bridgeboards, and boat booms.

The Canfield reel is a compact reel with uses similar to the A-pack reel but has the disadvantage of being designed for single conductor cable.

The A-55 reel is a more modern design of the old type A reel.

The B-50 reel was designed to replace the B-3 reel and the handcrank E reel which are both obsolete now. The B-50 reels made before 1960 are adaptable to power equipment but those made subsequently are not. The B-50 reel will probably be discontinued within a very short time and be replaced by the B-56 reel.

The B-56 reel is similar to the B-50 reel but has the advantage that it can be used as a handcrank reel or be used with power equipment.

The E-53 reel has replaced the old type D reel and is the largest reel commonly used by the USGS. The E-53 is designed exclusively for use with power equipment, but it is provided with a handcrank for emergency use.

Table 4 contains pertinent information on the six reels discussed above.

Ellsworth reverse-lay two-conductor cable is normally used on sounding reels. This cable is available in three sizes--0.084, 0.10, and 0.125-inch diameter.

The Ellsworth cable consists of an insulated core composed of copper conductor wires and stainless steel wires bunched together and wrapped in five or more layers of wax-saturated cotton. The insulated core is covered by 33 galvanized wires, of which the inner 15 are wrapped in one direction and the outer 18 are wrapped in the reverse direction. Wrapping the two layers of wires in reverse directions reduces the amount of twisting which ordinarily occurs when current meters and weights are suspended from such cables. The following table indicates the breaking strength of the various diameter Ellsworth cables:

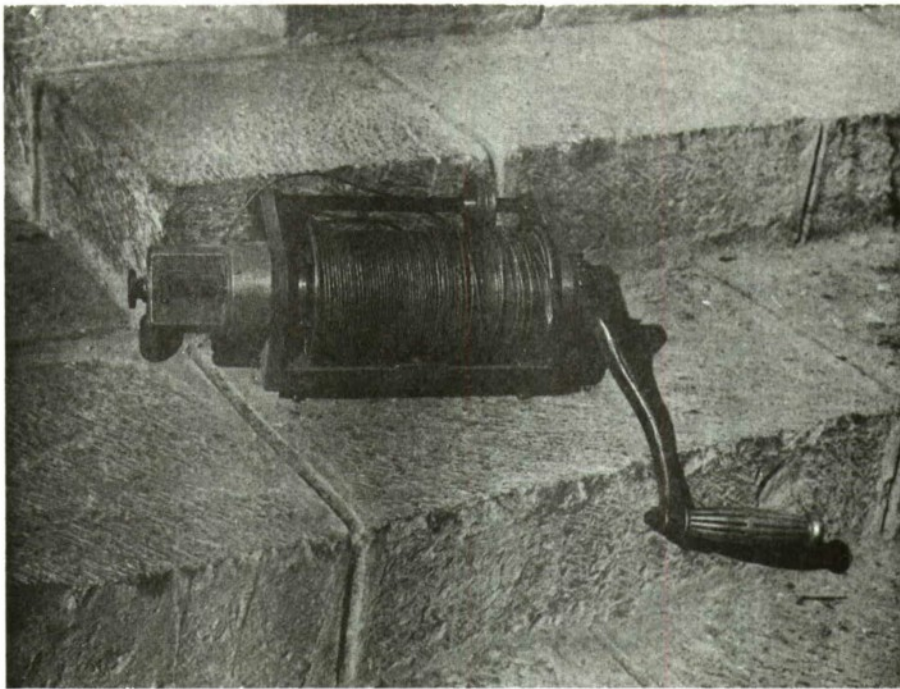


Figure 22.--Type A sounding reel.

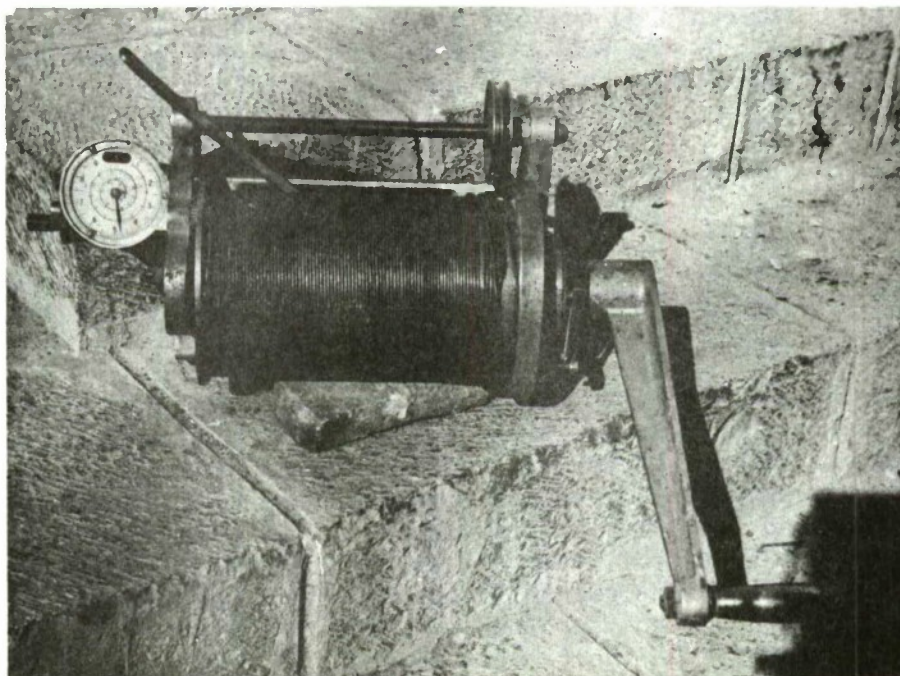


Figure 23.--Type B sounding reel with
computing type depth indicator.

Cable diameter (in)	Breaking strength (lbs)
0.084	400-600
.10	800-1,000
.125	1,500

It is important that the appropriate size cable-laying sheave be used on the reel.

1/16-inch diameter 7 x 7 galvanized steel aircraft cord is used on the single conductor Canfield reel.

A connector is used to join the end of the current-meter cable to the sounding weight hanger. Three types of connectors are used. The type B. connector is used with the A-55, B-50, B-56, and E-53 reels. The Au connector is used with the A-pack and Canfield reels although the pressed-sleeve type connector can be used on those reels. The pressed-sleeve type connector is used mainly on handlines.

A computing-type depth indicator is used on the A-55, B-50, B-56, and E-53 reels. The indicator is less than 3 inches in diameter, made of stainless steel and is equipped with nylon bushings which do not need to be oiled. The main dial is graduated in feet and tenths of a foot from 0 to 10-feet. The depth is indicated by a watch hand. The tens of feet are read on a numbered inner dial through an aperture near the top of the main dial.

The main dial has a graduated spiral to indicate the 0.8-depth position for depths up to 30-feet without requiring that position to be computed.

A power unit is available for use on the B-56 and E-53 reels to raise and lower the sounding weight and meter. The power unit can be used with 6, 12, 18, or 24 volt batteries. The power unit drives the reel by means of two V belts. A pistol grip switch is used to operate the power unit.

Table 4.--- Sounding reel data

Type reel	Type cable	Cable diameter	Drum circumference (feet)	Cable capacity (feet)	Maximum size weight recommended (pounds)	Depth indicator	Brake	Type operation
Canfield	Single conductor	1/16	1	45	50	Counter	No	Hand
A-pack	Ellsworth	0.08	1	45	50	Counter	No	Hand
A-55	Ellsworth	.08 .10	1	95 80	50 100	Self-computing	No	Hand
B-50	Ellsworth	.08 .10	1 1/2	180 150	50 150	Self-computing	Yes	Hand
B-56	Ellsworth	.10 .125	1 1/2	144 115	150 200	Self-computing	Yes	Hand or power
E-53	Ellsworth	.10 .125	2	206 165	150 400	Self-computing	Yes	Power

Handlines

Part 5.1.1.B.4

Handlines are used for making discharge measurements from bridges using a 15 or 30 pound sounding weight. The advantages of the handline are that it is easier to set up, eliminates the use of a sounding reel and the equipment to support the reel, and makes discharge measurements from bridges with vertical and diagonal members quicker and easier when light weights are being used. The disadvantages of the handline are that it requires more physical exertion especially in deep streams and there is a greater possibility of making errors in determining depth because of slippage of the handline or measuring device. Handlines can be used from cable cars but the use of them there is not recommended because of the disadvantages mentioned above.

A handline consists of the following parts:

1. Rubber-covered superservice cable (about 30-feet)
2. Handline reel
3. 0.10-inch diameter Ellsworth cable (about 40-feet)
4. Connector (see part 5.1.1.B.3)
5. Telephone plug

Number 16/2 rubber covered cable is recommended because it is easy on the hydrographer's hands when he is raising and lowering the sounding weight and meter.

There are two types of handline reels; the Lee-Au type and the Morgan type. The Lee-Au reel is an oval-shaped aluminum casting which can accommodate about 50 feet of Ellsworth cable. The advantage of this reel is that the cable can be wound on and off the reel very easily. The Morgan reel is made of stainless steel bars and its advantage lies in its light weight.

Ellsworth reverse lay cable is recommended for handlines rather than Kinnison direct lay cable previously recommended because of its greater flexibility and durability.

The pressed sleeve type connector or the Au connector are used on handlines because they are lighter in weight than the type B connector and because they are sufficiently strong for the size sounding weights used with handlines.

Width-measuring equipment

Part 5.1.1.C

Stationing of any point in a cross section is measured from an initial point on the bank. Cableways and bridges used regularly for making discharge measurements are commonly marked at 2, 5, 10 or 20-foot intervals by paintmarks. Stationing of points between the markings is estimated or measured with a rule or pocket tape.

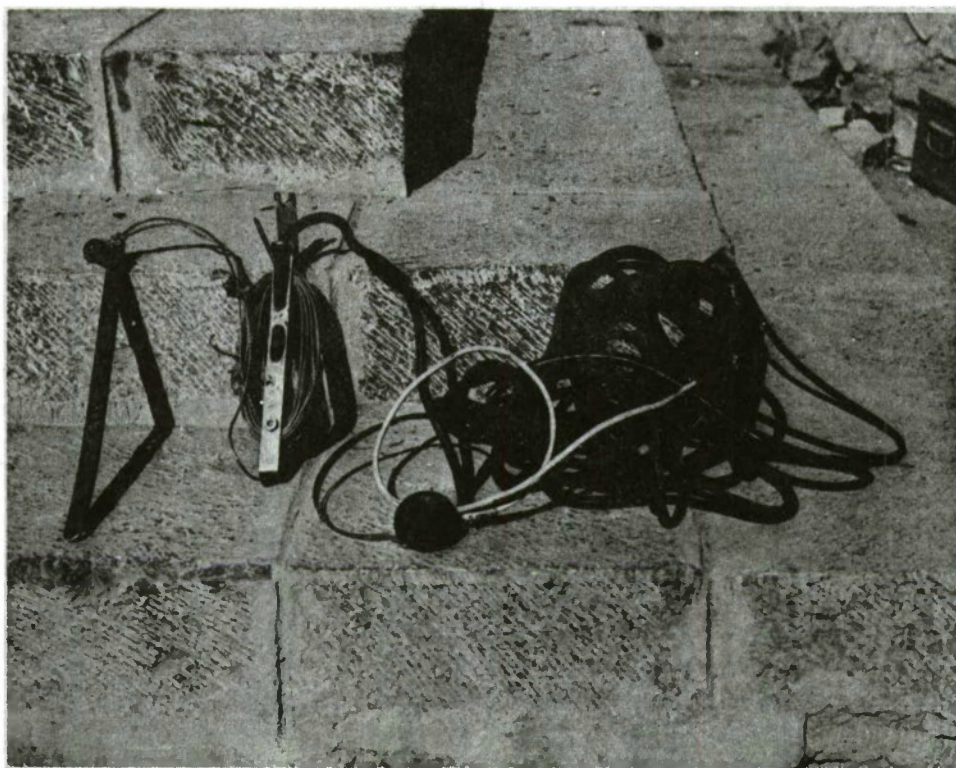


Figure 24.--Morgan handline reel with service cord and headphone.

For measurements made by wading or made from unstationed bridges, steel or metallic tapes or tag lines are used.

The tag lines are made of 1/32, 1/16, 3/32, or 1/8-inch diameter galvanized steel aircraft cord, and solder beads at measured intervals are used to indicate distances. The standard arrangement of solder beads or tags is:

No. of tags	Interval	Arrangement
1	2-foot	0' to 50'
1	5-foot	50' to 150'
1	10-foot	150' to end
2	-	0, 10, 20, 30, 40, 50, 150, 250, 350, etc.
3	-	All 100' points

The standard lengths of tag lines are 300, 400, and 500 feet but other sizes can be obtained by special order.

The tag lines are kept on tag line reels. There are three types of tag line reels in use:

1. Columbus type A
2. Pakron
3. Lee-Au

The Columbus type A tag line reel is 9-inches long and is made of aluminum bars. The capacity of the reel is 300-feet of 1/32-inch diameter steel cord.

The Pakron reel has a bracket with a hole in it attached to the rim of the reel. A rod can be placed through this hole and then driven in the ground to provide a support and anchor for the reel. The reel also has a brake which allows tension to be put in the line. The capacity of the Pakron reel is 300-feet of 1/32-inch diameter steel cord.

The Lee-Au tag line reel is circular, 8 1/4-inches in diameter, and made of cast aluminum. A removable hub and handle is available to make it easier to wind and unwind the tag line. The capacity of the reel is 500-feet of 1/16-inch diameter steel cord.

Larger reels, particularly those designed for use with boats are described in part 5.1.1.D.3.

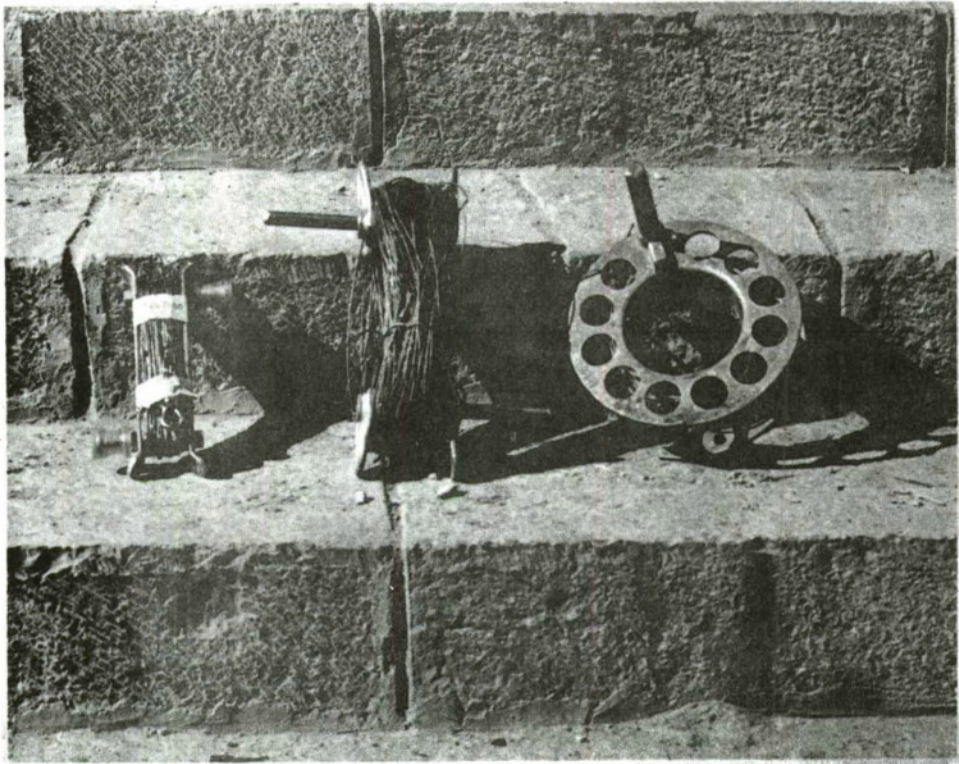


Figure 25.--Tagline reels with taglines.

Special equipment is necessary for each type of current meter measurement. The meters, weights and reels used have already been described and the equipment needed to support these items will be described in this section.

The special equipment assemblies have been divided into three groups:

1. Cableway equipment.
2. Bridge cranes and bridge boards.
3. Boat measuring equipment.

Cableway equipment

Part 5.1.1.D.1

Two types of cable cars are used in stream gaging: the sit-down type and the stand-up type. Normally, the sit-down type car is used for cableway spans less than 400 feet and where the lighter sounding weights are used; and the stand-up type cars are used on the longer spans and where heavy sounding weights are needed.

The cable cars are constructed of various materials and have variation in design depending on local preference and conditions. Some of the sit-down cars have wooden seats and sides while others are made of steel or aluminum. Some cars have one foot rest, others have two, some have roofs, some have permanent seats for the sounding reel while in others portable seats are used. Some of the sit-down cars have a follower brake. This brake is an overhead rod actuated brake to hold the car in one place on the cable. This type brake is almost essential on cars with sheave wheel guards. Some of the stand-up cars are also constructed with wooden sides and floors while others are made of steel or aluminum sections. All stand-up cars are equipped with permanent reel plates but some have the plates at the end of the car while others have them on the upstream side of the car. Some of the stand-up cars have follower brakes and many of them have roofs.

The cable cars are moved from one point to another on the cableway by means of cable car pullers. The standard cable car puller is a cast aluminum piece with a snubbing sprag attached. The snubbing sprag is usually four-ply belting, and when placed between one of the cable car sheaves and the cable will prevent movement of the cable car along the cable. A special puller is used with the follower brake. The third type of puller is the Colorado cable car puller which is the same in principle as the follower brake type.

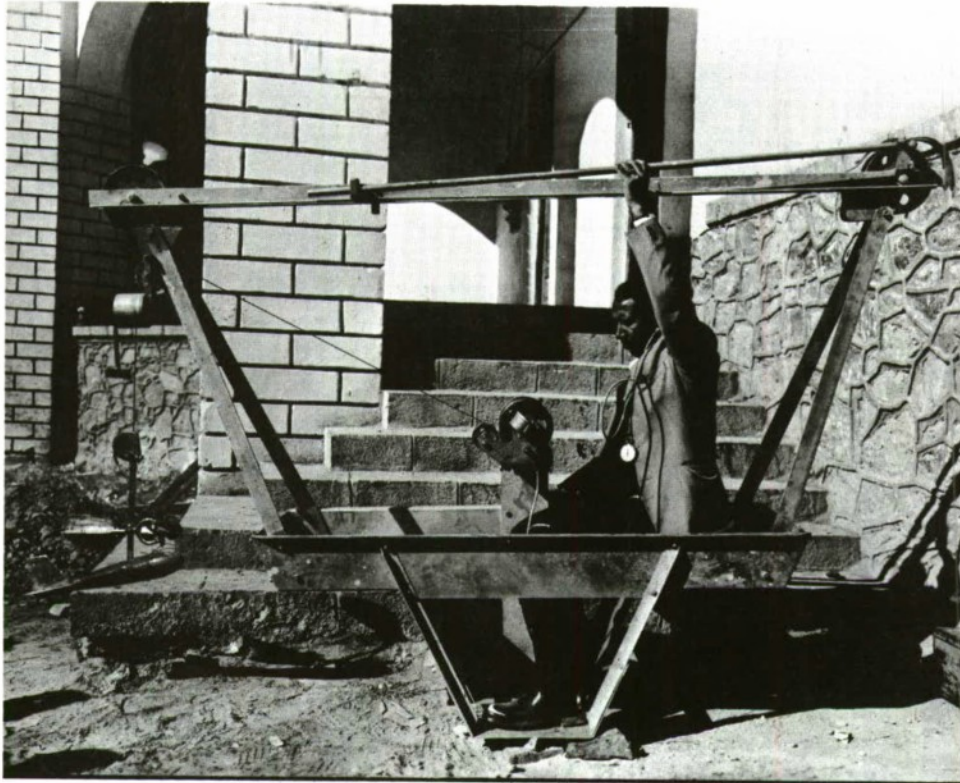


Figure 26.--Sit-down type cable car with follower type brake and vertical angle protractor. Sounding reel, current meter, and sounding weight are in position for measuring depth and velocity.



Figure 27.--Sit-down type cable car installed on cableway.



Figure 28.--Cable car pullers. Puller on right is for cable cars without follower brakes. Others are for follower-brake type cable cars and differ only for cable diameter.

The sit-down cable cars have a great variety of means of supporting the sounding reel. The A-pack and Canfield reels are designed to clamp on the side of the car. This arrangement works very well for the reels are light in weight and usually only light sounding weights are used with them. When larger reels are used reel seats which are either permanently attached to the cable car or portable are used.

The stand-up type cable cars have reel plates attached to the structural members of the cable car. There is usually a sheave attached to the structural members over which the sounding line passes so that the sounding weight and current meter will clear the bottom of the cable car. Power reels can also be used from cable cars.

The use of handlines from cable cars is not recommended (see part 5.1.1.B.4).

Many cable cars are equipped with protractors for measuring the vertical angles (see part 5.1.3.B).

Bridge cranes and bridge boards

Part 5.1.1.D.2

The meter and sounding weight used for measuring from a bridge can be supported by a handline, or by a sounding reel mounted on a crane or on a bridge board. The handline has been previously described in part 5.1.1.B.4.

Hand operated portable cranes are of two types: the type A to handle sounding weights up to 100 pounds, and the type E to handle sounding weights over 100 pounds. The type A crane can be used with two different types of trucks or bases. The three-wheel base consists of three 10-inch wheels - two in the front and one in the rear. The standard base has four 10-inch wheels with adjustable supports on the rear two. The type E crane consists of a super-structure or boom and base designed to support heavy sounding weights. A 48-inch extension to the type E superstructure is available.

All cranes are designed so that the superstructure can be tilted forward over the bridge rail far enough so that the meter and weight will clear the rail. Where bridge members are encountered when moving along the bridge, the weight and meter can be brought up to the superstructure and the superstructure tilted back in order to get by the obstructing bridge members.

Cast iron counter weights, weighing 60 pounds each are available for use with four-wheel base cranes. The number of such weights needed depends upon the size of the sounding weight being supported, the depth and velocity of the stream, and the amount of debris being carried by the stream.



Figure 29.--Four-wheel type A bridge crane with sounding reel, current meter, and sounding weight installed for use. Note counterweights on base of crane.

A fluid type protractor is available for use on cranes to measure the angle the sounding line makes with the vertical when the weight and meter are pushed downstream by the velocity of the water. The protractor consists of a graduated circle clamped to an aluminum plate. A plastic tube partly filled with colored anti-freeze fits in a groove between the graduated circle and the plate. A stainless-steel rod is attached to the lower end of the plate to ride against the outer edge of the sounding cable. The protractor will measure vertical angles from -25° to $+90^{\circ}$. That range is adequate for use on all of the present standard type A and type E cranes.

Bridgeboards may be used with a type A sounding reel and weights up to 50 pounds. A bridgeboard is usually a 2-in x 6-in plank about 6 to 8-feet long with a sheave at one end over which the meter cable passes and a reel seat near the other end. The board is placed on the bridge rail so that the force exerted by the sounding weight suspended from the reel cable is counterbalanced by the weight of the sounding reel and sometimes another counterweight on the reel end. The bridge board may be hinged at the center point and one end placed on the sidewalk or roadway when in use.

Boat measuring equipment

Part 5.1.1.D.3

Measurements made from boats require some special equipment that is not used for any other type measurement.

Extra large tag-line reels are necessary for use on wide streams. Three types of tag-line reels are available for boat measurements:

1. A heavy duty, horizontal axis reel without a brake, and with a capacity of 2,000-feet of 1/8-inch diameter cable.
2. A heavy duty, horizontal axis reel with a brake and with a capacity of 3,000-feet of 1/8-inch diameter cable.
3. A vertical axis reel without a brake and with a capacity of 800-feet of 1/8-inch diameter cable.

The brake on the second reel described above is quick-acting and can hold the tension of the tag line. The brake can be set for the desired drag when unspooling the cable. A ratchet and pawl are provided for use when there is a tendency for the brake to slip when the boat is tugging against the tag line. This reel is usually bolted to a plank and chained to a tree while in use. A utility line consisting of 30-feet of 3/32-inch diameter cable with a harness snap at one end and a pelican hook at the other is connected to the outer end of the boat tag line and fastened around a tree or post, thereby preventing damage to the tag line. The tag line is stationed at appropriate intervals.



Figure 30.--Boat measuring equipment set up for use.
Note tagline for holding boat on cross section
and quick release mechanism for freeing boat.

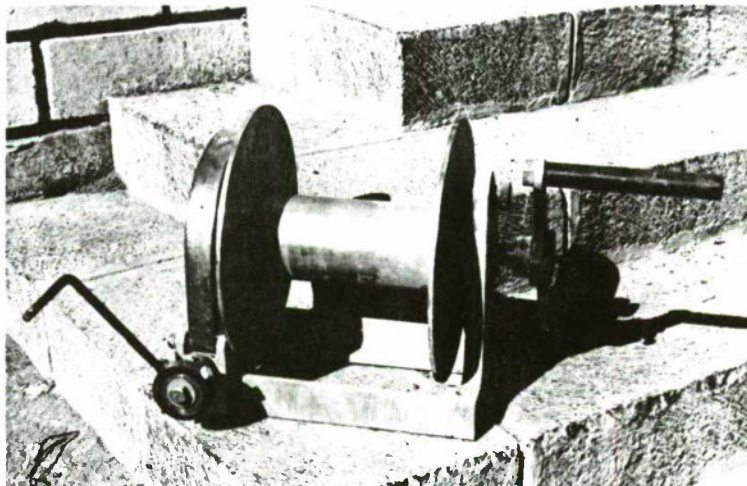


Figure 31.--Boat tagline reel with brake.

All sounding reels fit on the boat boom except the A-pack and the Canfield and they can be made to fit by drilling additional holes in the reel plate on the boom.

In addition to the above equipment, the following items are needed when making boat measurements:

1. A boat usually flat bottomed of sufficient size to support the hydrographers and necessary equipment.
2. A motor that can move the boat with ease against the maximum current in the stream.
3. A pair of oars for emergency use.
4. A life preserver for each hydrographer (which should be worn).
5. A bailing device.

Miscellaneous equipment

Part 5.1.1.E

Several miscellaneous items of equipment which have not been described are necessary when current meter measurements are made. The two classifications of equipment described in this part are:

1. Timers
2. Counting equipment

Timers

Part 5.1.1.E.1

In order to determine the velocity at a point with a current meter it is necessary to count the revolutions of the meter in a certain interval of time, usually 40 to 70 seconds. The velocity is then obtained from the meter rating table (see part 5.1.1.A.2). The time interval is measured with a stop watch to the nearest second.

The stop watch commonly used is a still-movement type graduated to the fifth of a second. One complete revolution of the large hand is made in 60 seconds. A smaller dial on the face of the watch indicates the number of minutes the watch has been running, up to 30 minutes. Depressing the stem of the watch starts it; a second depression of the stem will stop it; a third depression resets the watch to 0 seconds. The watches should be checked periodically to be certain they are correct and accurate.

Counting equipment

Part 5.1.1.E.2

The revolutions of the meter must be counted during the observation of velocity and the method used is to set up an electric circuit that is closed each time the contact wire touches the single or penta eccentric of the current meter. A battery and a headphone are part of the electrical circuit and a "click" is heard in the headphone each time the contact wire makes a contact. The headphone that is used is a 5 ohm receiver and the battery can be a 4.5 volt battery or a 1.5 volt flashlight battery or equivalent. Many hydrographers have adapted hearing-aid phones to replace the headphones because they are more compact and not as uncomfortable to use.

Recently a magnetic switch contact chamber has been developed to replace the contact wire contact chamber (see part 5.1.1.A.1). An automatic electric counter has been developed for use with the magnetic contact chamber. The electric counter is powered by four 1.5 volt flashlight batteries and is equipped with an on-off switch. The counter can count up to 999 and has a reset button. A metal clip is attached to the counter so that it may be easily clipped on the hydrographer's belt for ease in carrying. The electric counter should not be used with the contact wire contact chamber because at low velocities the contact wire drags thereby sending several signals to the counter for each revolution.

Measurement of velocity

Part 5.1.2

The current meter measures velocity at a point. The method of making discharge measurements at a cross section requires determination of the mean velocity in each of the selected verticals. The mean velocity in a vertical can be obtained from many observations of point velocity in that vertical or it can be approximated by fewer measured velocities and use of a known relation between the velocities at those points and the mean in the vertical. The various methods of measuring velocity to be described are:

1. Vertical-velocity curve method.
2. Two-point method.
3. Six-tenths depth method.
4. Two-tenths depth method.
5. Three-point method.
6. Subsurface method.

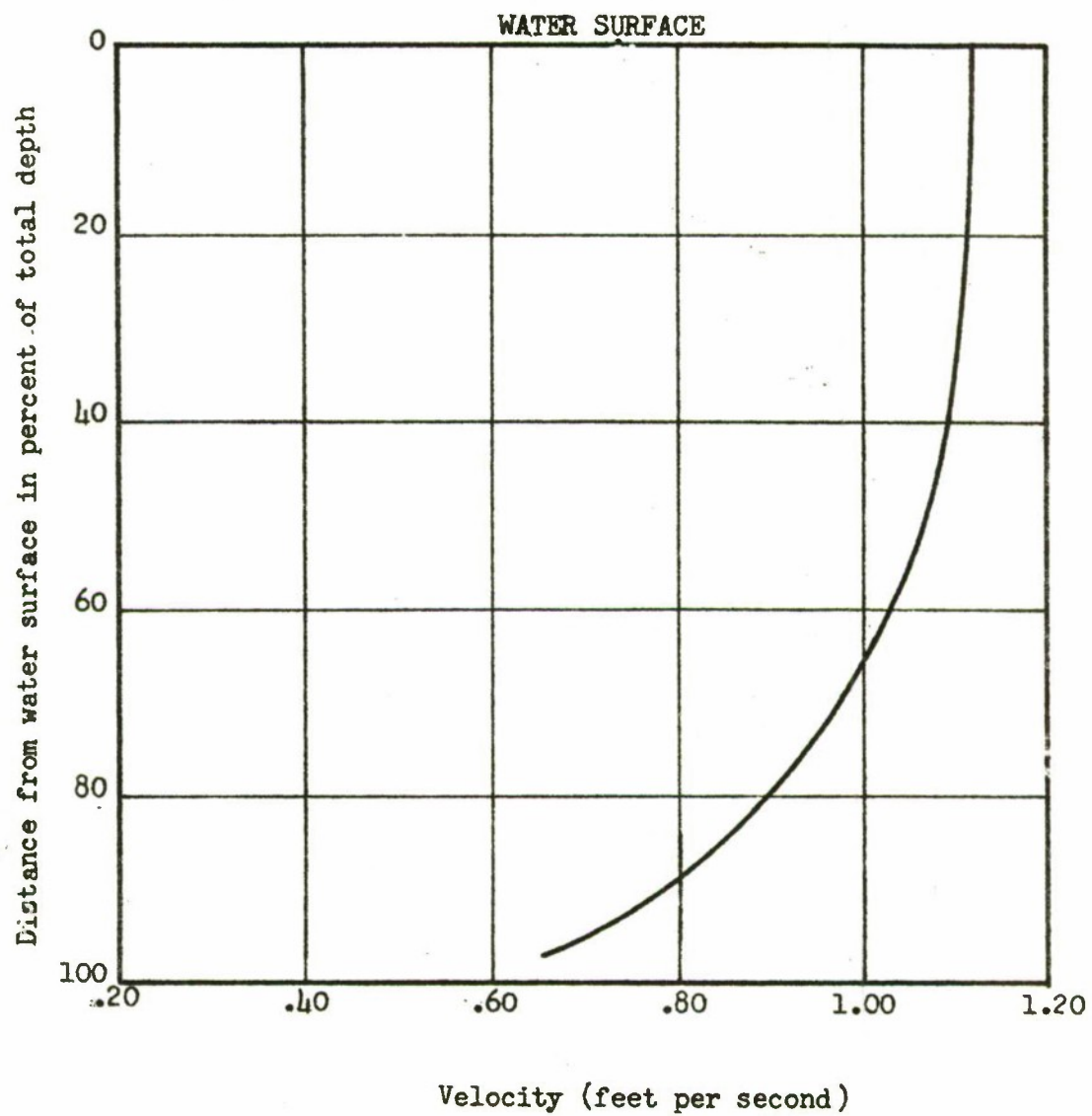


Figure 32.-- Typical vertical-velocity curve

Vertical-velocity curve method

Part 5.1.2.A-

In the vertical-velocity curve method a series of velocity observations at points well distributed between the water surface and the streambed is made at each of the verticals. If there is considerable curvature in the lower part of the vertical-velocity curve, it is advisable to space the observations more closely in that part of the depth. Normally, the observations are taken at 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 of the depth. Observations should always be taken at 0.2, 0.6, and 0.8 of the depth so that the results obtained by the vertical-velocity curve method may be compared with the commonly used methods of velocity observation. Observations should be made at least 0.5-foot from the water surface or from the streambed when using the Price type AA meter or the vane-type meter and should be made at least 0.3-foot from these boundaries when the Price pygmy meter is used.

The vertical-velocity curve for each vertical is based on observed velocities plotted against depth (see fig. 31). In order that vertical-velocity curves at different verticals may be readily compared, it is customary to plot depths as proportional parts of the total depth. The mean velocity in the vertical is obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, dividing the area by the length of the ordinate axis, and finally laying the resulting length along the abscissa axis and reading the mean velocity.

The vertical velocity curve method is valuable in determining coefficients for application to the results obtained by other methods. The method is not generally adapted to the making of routine discharge measurements because of the time required to collect the field data and the cumbersome work necessary to compute the mean velocity.

Two-point method

Part 5.1.2.B

In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of these two observations is taken as the mean velocity in the vertical.

The two-point method is based on many studies of actual observation and on mathematical theory. Experience has shown that this method gives more consistent and accurate results than any of the other methods except the vertical-velocity curve method, and the two-point method is the one generally used by the USGS.

The two-point method should not be used at depths less than 2.5-feet because the current meter will be too close to the water surface and to the streambed to give dependable results.

Six-tenths depth method

Part 5.1.2.C

In the 0.6-depth method, an observation of velocity made at 0.6 of the depth below the surface in the vertical is used as the mean velocity in the vertical. Actual observation and mathematical theory have shown that the 0.6-depth method gives reliable results.

The 0.6-depth method is used under the following conditions:

1. Whenever the depth is less than 2.5-feet or greater than 0.3-foot. The 0.6-depth method and the pygmy meter are used for depths from 0.3-foot to 1.5-feet when sailing.
2. When large amounts of slush ice or debris are flowing, making it impossible to accurately observe the velocity at the 0.2-depth, thus preventing the use of the two-point method.
3. When the meter is placed a distance above the sounding weight for cable suspension where it is impossible to place the meter at the 0.8-depth setting.
4. When the stage in a stream is changing rapidly and a measurement must be made quickly, the 0.6-depth method is sometimes used instead of the two-point method to save time.

Two-tenths depth method

Part 5.1.2.D

The two-tenths depth method consists of observing the velocity at 0.2 of the depth below the surface, and then applying a coefficient to the observed velocity to obtain the mean in the vertical. It is used mainly during times of high water when the velocities are great, and large amounts of debris or ice are flowing, and it is impossible to obtain soundings or to place the meter at the 0.8-depth or the 0.6-depth. A standard cross section must be available to compute the 0.2-depth when it is impossible to obtain soundings (see part 5.1.1). The two-point method and the 0.6-depth method are preferred by the USGS over the 0.2-depth method because of their greater accuracy.

The measurement is normally computed by using the 0.2-depth velocity observations without coefficients as though each was a mean in the vertical. The approximate discharge thus obtained divided by the area of the measuring section gives the weighted mean value of the 0.2-depth velocity. Studies of many measurements made by the two-point method show that for a given measuring section the relation between the mean 0.2-depth velocity and the true mean velocity either remains constant or varies uniformly with stage. In either case, this relation may be determined for a particular 0.2-depth measurement by recomputing measurements made at the site by the two-point method using only the 0.2-depth velocity observation as the mean in the vertical. The plotting of the true mean velocity versus the mean 0.2-depth velocity for each measurement will give a velocity-relation curve for use in adjusting the mean velocity for measurements made by the 0.2-depth method.

If there are not enough previous measurements at a site that have been made by the two-point method to establish a velocity-relation curve for the 0.2-depth method, it is necessary to define vertical velocity curves subsequently at lower stages to establish a relationship between the mean velocity and the velocity at 0.2 depth. The usual coefficient to adjust the 0.2-depth velocity to the mean velocity is 0.88.

Three-point method

Part 5.1.2.E

The three-point method consists of observing the velocity at 0.2, 0.6, and 0.8 of the depth, thereby combining the two-point and 0.6-depth methods. The mean velocity is computed by averaging the 0.2- and 0.8-depth observations and then averaging the result with the 0.6-depth observation, or if it is desired to give more weight to the 0.2- and 0.8-depth observations, the arithmetical mean of the three observations may be used; however, the first procedure is normally used.

This method is used when the velocities in the vertical are abnormally distributed or if the 0.8-depth observation is made where the velocity is seriously affected by friction or by turbulence produced by the streambed or an obstruction in the stream. The depths must be greater than 2.5-feet before this method can be used.

Subsurface method

Part 5.1.2.F

The subsurface method consists of observing the velocity at some uniform distance below the water surface. This distance should be at least 2-feet and preferably more for deep, swift streams to avoid the effect of surface disturbances.

This method is used during periods of high water when it is impossible to obtain soundings and a standard cross section is not available for computing the 0.2-depth setting. Coefficients are necessary to convert the velocities observed by the subsurface method to the mean velocity in the vertical. Vertical-velocity curves must be obtained subsequently at a lower stage to compute these coefficients. It is generally difficult to determine these coefficients accurately because they may vary with stage, depth, and position in the measuring cross section.

Current-meter measurement procedure

Part 5.1.3

The first step in making a current-meter measurement is the selection of the cross section to be used. The reach of stream containing the selected cross section should have the following characteristics:

1. The reach should be straight and the threads of velocity parallel to each other.
2. Stable streambed free of large rocks, weeds, and protruding obstructions such as piers, which would create turbulence.
3. The profile of the streambed in the reach should be flat to eliminate any vertical component of velocity.

It is usually not possible to satisfy all of these conditions, but the best possible site using these criteria should be selected.

After the cross section has been selected, the next step is to determine the width of the stream. This is done by stringing a tag line or measuring tape for measurements made by wading, from a boat, from ice cover, or from a bridge. The line should be strung at right angles to the direction of flow to avoid horizontal angles in the cross section. If a cableway is used, the graduations painted on the cable can be used to determine the width.

When the total width is known, the spacing of the verticals can be determined. Normally, about 25 to 30 partial sections are used, but with a smooth cross section and good velocity distribution fewer sections may be used. The partial sections should be so spaced that no partial section has more than 10 percent of the total discharge in it. The ideal measurement is one in which no partial section has more than 5 percent of the total discharge in it, but this is very seldom accomplished when 25 partial sections are used. Equal widths of partial sections across the entire cross section are not recommended unless the discharge is well distributed. The width of the partial sections should be less where depths and velocities are greater.

Next, the appropriate equipment is assembled for the current-meter measurement. The size sounding weight used in current-meter measurements depends on the depth and velocity to be encountered in a cross section. A good rule of thumb is that the size of the weight in pounds should be greater than the maximum product of velocity and depth in the cross section selected. If it is impossible to follow this rule, the sounding line supporting the sounding weight will not remain in a vertical plane. If debris or ice are flowing or it is extremely windy, especially when measuring from a cableway, this rule does not hold except that it at least provides a starting point for deciding on the size weight necessary. Previous measurements at a site can be scanned to determine the size weight needed at various stages.

The observations made during a discharge measurement are recorded on discharge measurement note sheets. At the top of each discharge measurement note sheet, the following information should be recorded:

1. Name of stream referenced to a nearby village.
2. Date.
3. Type of meter suspension.
4. Meter number.
5. Time measurement was started (military time is used).
6. Which side of stream was the starting point.

Item 6 is usually symbolized by either LEW or REW, which stand for left edge of water and right edge of water respectively. Determining left from right is done with the hydrographer facing downstream. During the course of the measurement, the time should be recorded in the notes periodically, usually at 15-minute intervals. The time is important because if there has been any appreciable change in stage during the measurement, the time will be needed to weight the mean gage height for the measurement. When the measurement is completed, the time and the side of the stream the hydrographer finished on should be recorded on the note sheet.

After the equipment and the note sheet have been readied, the measurement is begun. The hydrographer indicates on his note sheet the distance from the initial point to the edge of the water. If there is depth at the edge of the water, he measures the depth of water and records it. The depth is measured by using a graduated rod, by using a sounding reel with a depth indicator, or by using a handline.

Tags are oftentimes placed on the sounding line a known distance above the center of the meter cups as an aid in determining depth. The tags, which are usually streamers of different colored binding tape, are fastened to the sounding line by solder beads or by small cable clips. Tags can be used for determining depth in two ways:

1. With the sounding weight on the streambed, the depth is determined by raising the weight until the first tag below the water surface is at the water surface. The total depth is then the sum of (a) the distance the weight was raised to bring the tag to the water surface, (b) the distance the tag is above the center of the meter cups, and (c) the distance from the bottom of the weight to the center of the cups. This method is sometimes used with handlines.
2. The tag can be used as the reference for the water surface rather than the meter cups. The procedure is to set the tag at the water surface and then set on the depth indicator the distance that particular tag is above the center of the meter cups. The procedure then is the same as if the meter cups themselves had been set at the water surface. This is the preferred procedure. If debris or ice are flowing, this method is used to prevent damage to the meter.

If the air temperature is considerably below freezing, it is recommended that tags be used, thereby keeping the current meter in the water at all times, thus preventing it from freezing. Tags are also used in the measurement of deep, swift streams.

After determining the depth, the hydrographer decides on what method of velocity measurement he will use based on the depth. Normally then the two-point method or the 0.6 depth method is used. The setting of the meter for the particular method to be used is computed and the meter is placed at that depth. After the current meter is placed at the proper depth in the vertical it should be permitted to become adjusted to the current before the observation of velocity is started. The time required for such adjustment is usually only a few seconds if the velocities are greater than 1-foot per second, but for lower velocities, particularly if the current meter is suspended by a cable, a longer period of adjustment is needed. After the meter has become adjusted to the current, the number of revolutions made by the rotor of the current meter is observed for a period of 40 to 70 seconds. Observation of time to the nearest second is sufficient. The number of revolutions and the time interval is then recorded in the notes. If the velocity is to be observed at more than one point in the vertical the meter setting is determined for the additional observation and the revolutions are timed and the data recorded. The hydrographer then moves to the next vertical and repeats this procedure recording the distance from initial point, depth, revolutions, and time interval, and then on to the next vertical until the entire cross section has been traversed.

If the direction of flow is not at right angles to the cross section, the angle that the flow makes with a flow line that would be at right angles to the tag line must be measured. The horizontal angle (see sketch on next page) as it is called, is measured by holding the note

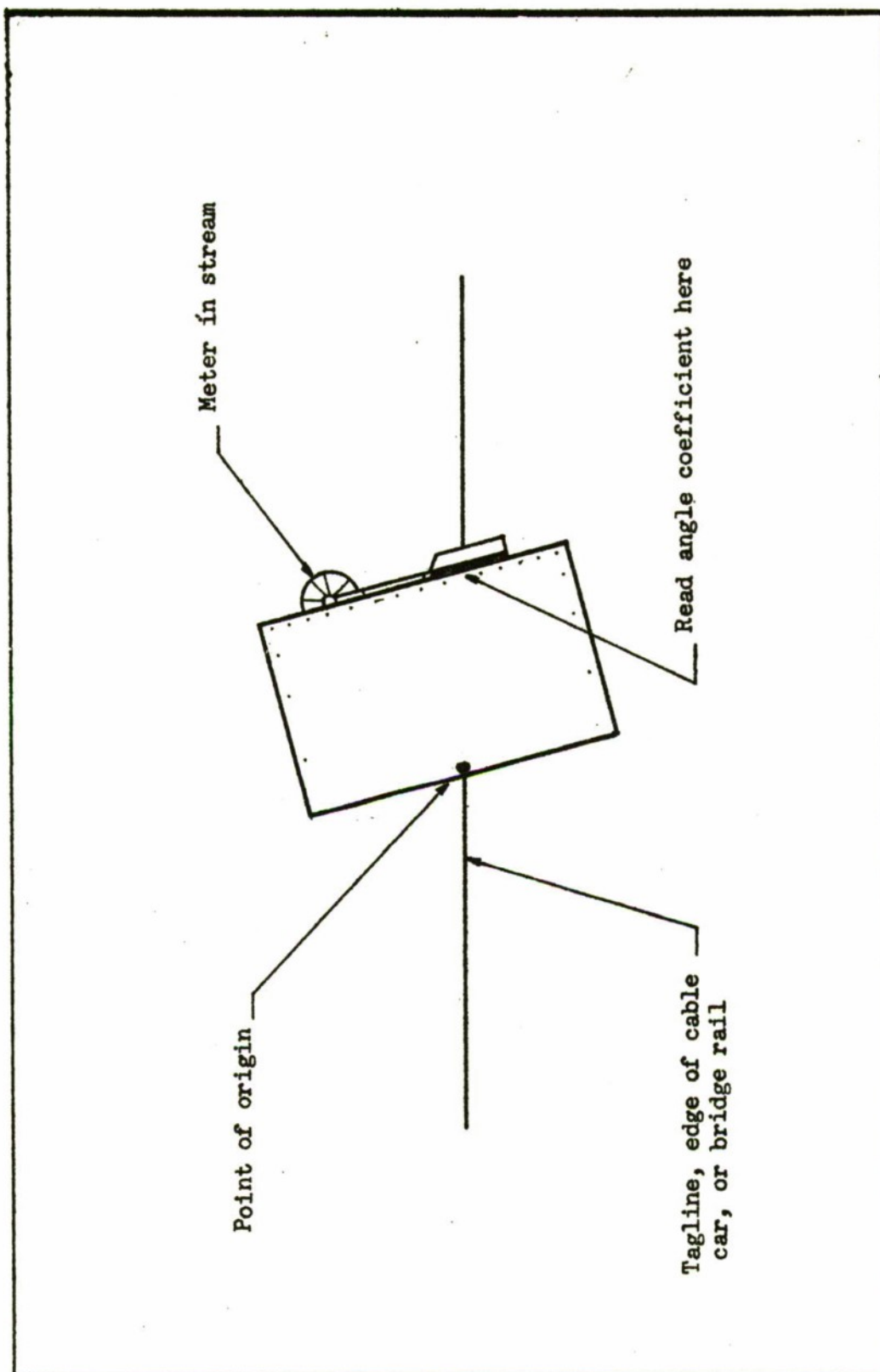
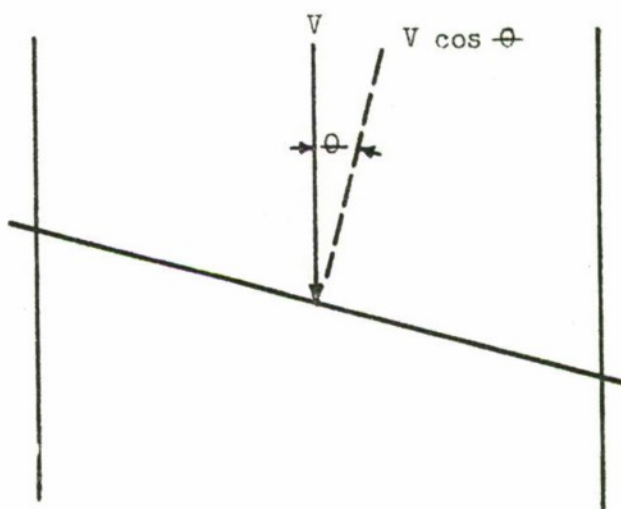


Figure 33.---Measurement of horizontal angles.

sheet in a horizontal position with the point of origin (θ) on the left edge of the note sheet over the tag line, bridge rail or any other feature parallel to the direction of flow, the tag line or bridge rail will intersect the value of the cosine of the angle on the top, bottom, or right edge of the note sheet. The cosine of the angle is then multiplied by the measured velocity to determine the velocity component normal to the measuring section.

The air temperature and water temperature should be determined and recorded on the note sheet for each current meter measurement. The air temperature should be determined in the shade and the water temperature should be read while the thermometer is still in the water. The air temperature should be determined first to be certain that a dry thermometer is used.



Wading measurements

Part 5.1.3.A

Wading measurements require considerable care to attain the precision common to other types of measurements. The tentative procedures recommended here for wading measurements are based on the results of many studies of current-meter performance and of velocity distribution at shallow depths. These recommendations may be modified after additional tests are made.

The following table lists the appropriate meter and placement of meter recommended for various depths:

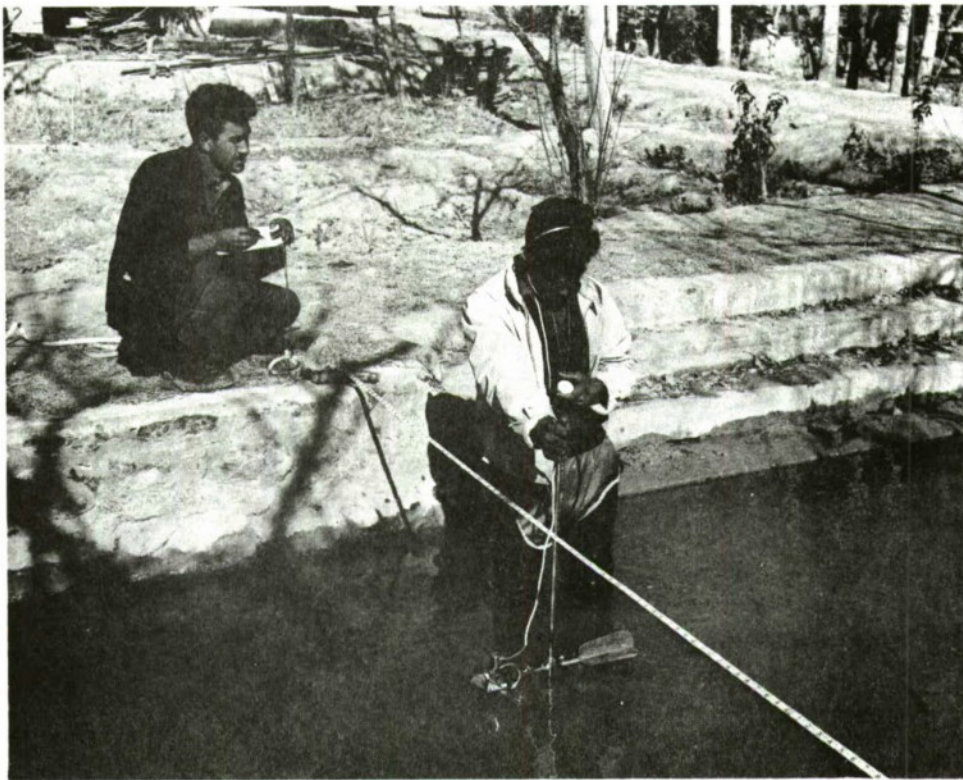


Figure 34.--Current-meter measurement by wading.

Depth		Meter	Method
Feet	Meters		
2.5 and above	0.75 and above	Type A or AA	0.2d - 0.8d
1.5 to 2.5	0.45 to 0.75	Type A or AA	0.6d
0.3 to 1.5	0.10 to 0.45	Pygmy	0.6d

A type AA meter used in a cross section with an average depth greater than 1.5-feet need not be changed to the Pygmy meter for a few depths less than 1.5 or vice versa. The type AA meter may be used at depths as shallow as 0.5-foot, but its use is not recommended below depths of 1.5-feet because the registration of the meter is affected by its proximity to the water surface and to the streambed. For example, the 0.6-depth setting of the meter for a total depth of 1.0-foot would be 0.4-foot from the streambed - so close that the type AA meter would underregister an amount that depends on velocity and bed roughness. The type AA meter and the Pygmy meter should not be used at velocities less than 0.2-foot per second because the rating of the meters below that point is not reliable.

When natural conditions for measuring are in the range considered un dependable, the measuring cross section should be modified to provide acceptable conditions. Many times it is possible to build dikes to cut off dead water and shallow flows in a cross section. The cross section can also be improved by removing the rocks and debris in the section and from the reach of stream immediately upstream from the measuring cross section. After modifying a cross section, the flow should be allowed to stabilize before starting the discharge measurement.

Reliable results may be obtained under the above acceptable conditions of depth and velocity only if the meter is in good condition. The minimum permissible spin for a type AA meter is 1.5 minutes and for a Pygmy meter 0.5 minute, and these times are permissible only if the bucket wheel comes to a smooth gradual stop. It is recommended that the meters be rerated at least every ten years. The pivot and pivot bearing of the meter should be inspected after each measurement, and as soon as a pivot or bearing begins to show wear it should be replaced.

The hydrographer should stand in a position that least affects the velocity of the water passing the current meter, which is: With the meter rod at the tag line and facing the bank with the water flowing against the side of his leg, the hydrographer should stand from 1 to 3-inches downstream from the tag line and 18-inches or more from the meter rod. Care should be exercised in making wading measurements of

narrow streams or those where the feet and legs of the hydrographer standing in the water occupy a considerable percentage of the cross section. In small streams where the width will permit, the hydrographer should stand on a plank or other support rather than in the water.

Care should be exercised in measuring streams with shifting beds, that the scoured depressions left by the hydrographer's feet do not affect soundings or velocities. Generally, the hydrographer had best measure ahead of and upstream from the direction he faces in crossing the section.

Discharge measurements from cableways

Part 5.1.3.B

The Price type AA current meter is generally used when making discharge measurements from a cableway. The depth is measured by using a sounding reel and the velocity is measured by setting the meter at the position in the vertical as indicated in the following table:

15 C .5, 30 C .5		50 C .55	
Depth (ft)	Meter setting	Depth (ft)	Meter setting
2.5 and over	0.2 and 0.8	2.8 and over	0.2 and 0.8
1.2 to 2.4	0.6	1.4 to 2.7	0.6
Below 1.2	Estimate velocity	Below 1.4	Estimate velocity
50 C .9		75 C 1.0, 100 C 1.0, 150 C 1.0	
Depth (ft)	Meter setting	Depth (ft)	Meter setting
4.5 and over	0.2 and 0.8	5.0 and over	0.2 and 0.8
2.2 to 4.4	0.6	2.5 to 4.9	0.6
Below 2.2	Estimate velocity	Below 2.5	Estimate velocity

The use of handlines from cableways is not recommended.

One problem encountered observing velocities from a cableway is that the movement of the cable car from one station to the next makes the car oscillate for a short time after coming to a stop. The counting of the revolutions of the meter should not be begun until this oscillation has dampened to a negligible amount.

If large amounts of debris are flowing in the stream, the meter should be raised up to the cable car several times during the measurement to be certain the pivot and cups of the meter are free of debris; however, the meter should not be raised out of the water during the measurement if the air temperature is considerably below freezing. The hydrographer should carry a pair of lineman's pliers with side cutters with him when making measurements from a cableway. If the weight and meter become caught on a submerged object or caught on floating debris and it is impossible to release them the sounding line may be cut to insure the safety of the hydrographer.

When measurements are made from cableways where the stream is deep and swift, it is necessary to measure the angle that the meter suspension cable makes with the vertical due to the drag caused by the deep, swift stream. This angle is needed to correct the soundings to obtain the actual vertical depth. Measurement of this vertical angle will be discussed in detail in a later section.

Measurement of discharge from bridges

Part 5.1.3.C

When a stream cannot be waded existing bridges may be used for current meter measurements. Many measuring sections under bridges are satisfactory for current-meter measurements but in general better results can be obtained from a cableway.

No set rule can be given for choosing between the upstream or downstream side of the bridge for a discharge measurement. The advantages of using the upstream side of the bridge are:

1. The hydraulic characteristics of bridge openings make the upstream side the one where greater accuracy of measurement can be attained.
2. Approaching drift may be seen and more easily avoided.
3. The upstream side of the bridge is not likely to scour as badly as the downstream side.

The advantages of using the downstream side of the bridge are:

1. Vertical angles can be easily measured on the downstream side for the sounding line will be moving away from the bridge and this fact will eliminate contact between the sounding line and the bridge members which might occur on the upstream side.
2. The flow lines of the stream may be straightened out by passing through a bridge opening with piers.

Whether to use the upstream side or the downstream side of a bridge for a current-meter measurement should be decided individually for each bridge after considering the factors mentioned above and the physical conditions at the bridge such as location of the walkway and traffic hazards.

Either a handline or a sounding reel supported by a bridge board or a portable crane is used for supporting the current meter and sounding weight from bridges. The type AA Price meter is used and it should be kept free of debris during the measurement.

The velocity is measured by setting the meter at the position in the vertical as indicated in the table in the section "Discharge measurements from cableways". The hydrographer should keep his equipment several feet from piers and abutments if velocities are high; the depth and velocity next to the pier or abutment are estimated on the basis of the observations at the nearest vertical to the pier.

If there are piers in the cross section it is usually necessary to use more than 25 to 30 partial sections in order that the resulting discharge be as accurate as would have been obtained in a similar section without piers. Piers will often cause horizontal angles which should be carefully measured. They also cause rapid changes in the horizontal velocity distribution in the section.

Foot bridges are sometimes designed and built to provide facilities for measuring canals, tailraces, and small streams. Rod suspension may be used from these foot bridges. For low velocities the procedure is the same as for a wading measurement but for higher velocities the depth should be obtained by the difference in readings obtained at an index point on the bridge when the base plate of the rod is at the water surface and on the streambed. Measuring the depth in this manner will eliminate the errors caused by the piling up of water on the upstream face of the rod.

When using a handline the sounding weight is lowered to the streambed, then the weight is raised until one of the tags is at the water surface. The distance the weight is raised is measured along the rubber covered service cord with a steel or metallic tape or a graduated rod. The total depth of water is then the summation of (1) the distance the particular tag is above the meter cups, (2) the measured distance the meter and weight was raised, and (3) the distance from the bottom of the weight to the meter cups.

Another method, used for shallow depths, is to set the meter cups at the water surface and then lower the sounding weight to the streambed while measuring by one of the methods mentioned previously the amount of rubber-covered service cord that has been let out. This measured distance plus the distance from the bottom of the sounding weight to the meter cups is the depth of water. When using a handline enough cable is unwound from the handline reel so that the reel will not be in the water when the sounding weight is on the streambed at the

deepest part of the cross section. If the bridge is high enough above the water surface the hydrographer will be able to raise and lower the weight and meter by using the service cord and will not have to raise or lower the equipment by the base cable. When the proper setting of the meter has been made for the velocity observation, the hydrographer may stand on the service cord to hold the meter in place and thereby free his hands to record the data.

In working from a truss bridge the handline may be disconnected from the earphone or counter wire and passed around a truss member with the sounding weight on the bottom. This obviates the need for raising the weight and meter to the bridge each time a move from one vertical to another is made, and is the principal advantage of a handline.

Discharge measurements from boats

Part 5.1.3.D

Measurements of discharge from boats are made at locations where no cableways or suitable bridges are available and where the stream is too deep to wade. One limiting factor in the use of boats is the velocity of the water, for the safety of the hydrographer must be of prime importance.

After selecting the measuring section the tag line is strung by allowing the line to unspool as the boat moves across the stream. Some tag line reels are equipped with brakes to keep the line taut while unspooling the cable (see part 5.1.1.D.3). Normally the slack is taken out of a tag line without a brake after it has been stretched across the stream by means of a block and tackle attached to the tag line reel and to an anchored support on the bank.

If the maximum depth in the cross section is less than 10-feet and the velocity is low, a rod can be used for measuring the depth and supporting the current meter. For greater depths cable suspension with a reel and sounding weight should be used.

The vane-type current meter with cable suspension yoke is recommended for use in measurements from a boat when the velocity is 0.5-foot per second or more. When the velocity is between 0.2-foot per second and 0.5-foot per second, the type AA Price meter is recommended except when the water surface is rough, or when there is a strong wind. The big advantage of the vane-type meter is that it does not measure the vertical component of velocity so that the bobbing of the boat should have little or no affect on its accuracy. The vane-type meter does not rate as well as the Price meter at low velocities therefore the Price meter is recommended for the lower velocities.

The procedure for making measurements from a boat is not different than that used for measurements from bridge or cableway once the special equipment has been set up. The equipment needed is described in part 5.1.1.D.3.

In order to make a discharge measurement when ice covers a stream, holes are chopped or drilled through the ice and the current meter is suspended through the holes. Measurements of discharge under ice cover are made under the most severe conditions but are normally extremely important because a large portion of the discharge record during a winter period may depend on one measurement.

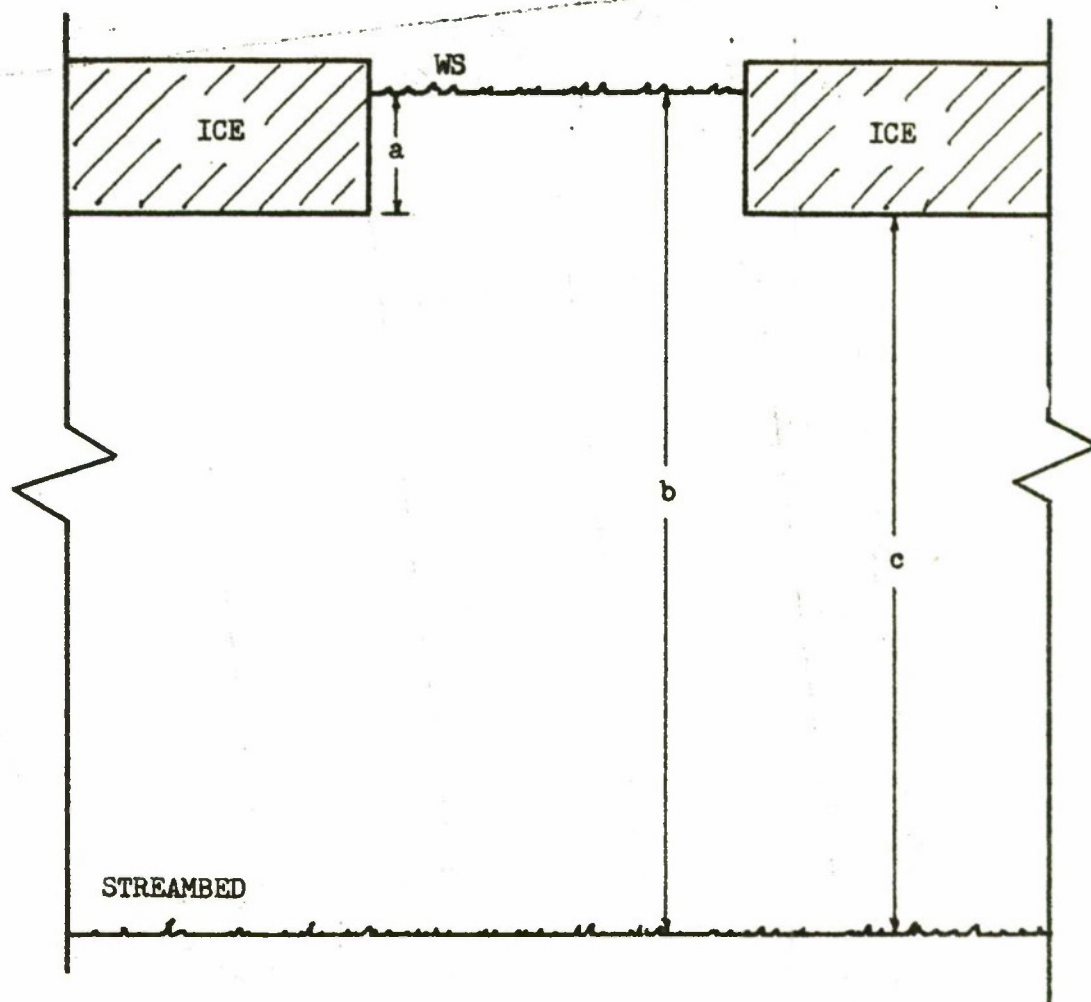
The location of the cross section used for a discharge measurement under ice cover should be selected during the open-water season when it is possible to evaluate the various cross sections available.

The hydrographer should exercise care when walking on the ice cover of a stream. The best procedure to follow in crossing the ice is to make frequent tests of the strength of the ice with a 13-pound ice chisel. If the blade of the chisel does not go through when the ice is struck a solid blow with the chisel then the ice is safe to walk on.

The first three holes in the selected cross section should be cut at the quarter points to detect the presence of slush ice in the measuring section. If slush ice is detected in the section selected during the open-water season, other sections should be investigated to determine if a section is available that is free of slush ice. If no section is completely free of slush ice, the section with the least amount of slush should be used. At least twenty holes should be spaced so that no partial section has more than 10 percent of the total discharge in it. This spacing also should be defined during the openwater season if possible.

At each hole it is necessary to determine the effective depth of the water (see figure 35) which equals the total depth of water minus the distance from the water surface to the bottom of the ice. The vertical pulsation of water in the holes in the ice must be given careful attention in determining the depths. The total depth of water is usually measured with a wadin rod or with a sounding weight and reel, depending on the depth.

A bar about 4-feet long, made of strap steel 1 1/2-inches by 1/8-inch, graduated in feet and tenths or meters and centimeters, and having a L-shaped projection at the lower end is generally used for measuring the distance from the water surface to the bottom of the ice. The horizontal part of the L should be 4-inches long so that it may extend beyond any irregularities on the under side of the ice. This rod is generally



a = Water surface to bottom of ice.

b = Total depth of water.

c = Effective depth ($c = b - a$).

0.2 depth setting

$$a + 0.2 c$$

0.8 depth setting

$$b - 0.2 c$$

0.6 depth setting

$$b - 0.4 c$$

Figure 35.--Method of computing meter settings

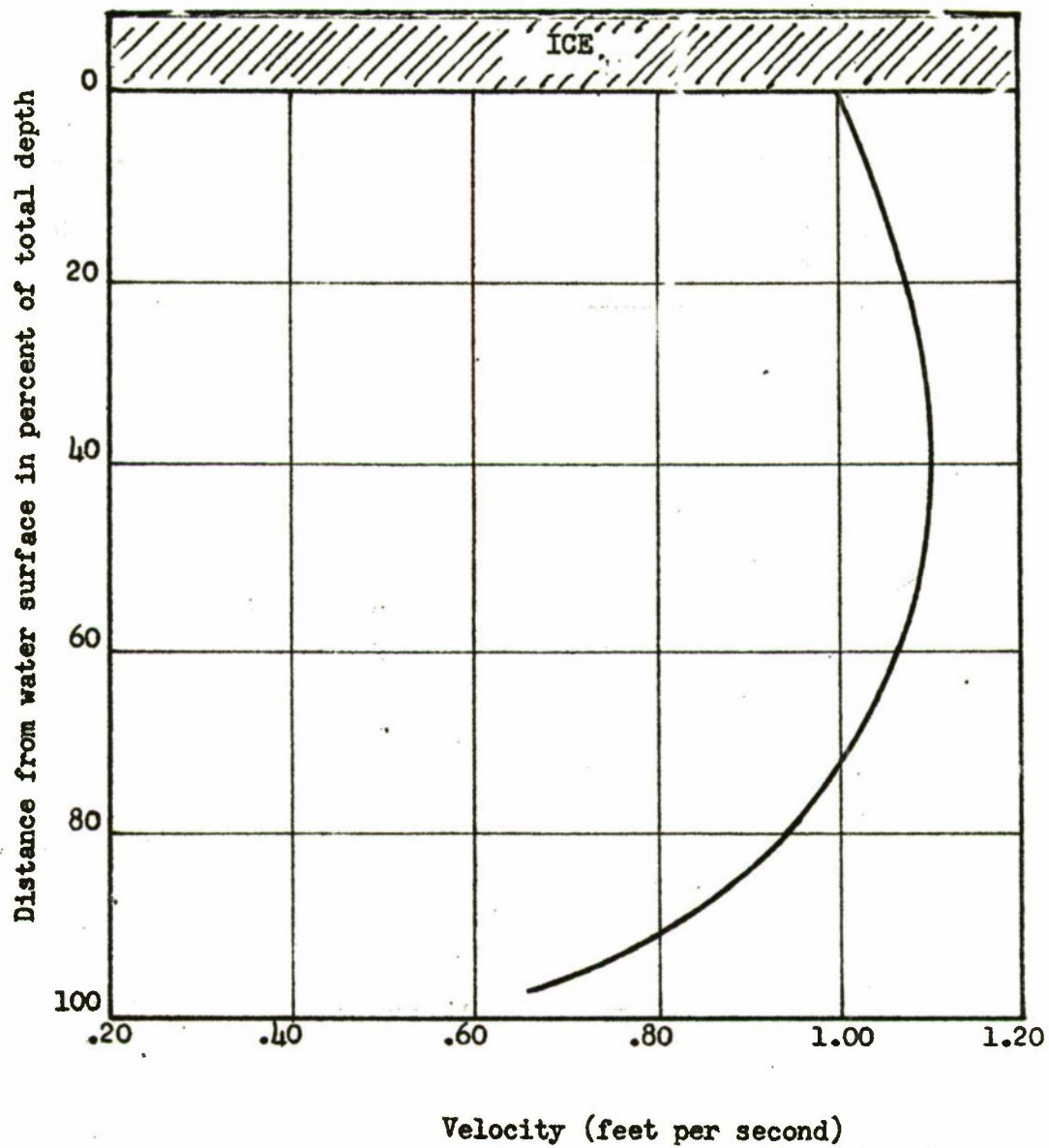


Figure 36.--Typical vertical-velocity curve under ice cover.

called an ice-measuring stick. If there is slush ice under the solid ice at a hole, the ice-measuring stick cannot be used to measure the distance from the water surface to the bottom of the ice. To find the depth at which the slush ice ends it is necessary to suspend the current meter down far enough in the hole that it is below the slush ice and the meter cups or vanes are turning freely. The current meter is raised slowly until the revolutions of the meter stop and this is the depth of the interface between water and slush.

After the effective depth of the water has been determined, the proper position of the meter in the vertical can be computed as shown in figure 35.

The new vane type ice meter is recommended for use under ice cover because of the following characteristics: (1) the vanes cannot become filled with slush ice as the cups of the Price meter often do, (2) the yoke of the vane type meter will fit in the hole made by the ice chisel more easily than the Price meter, and the yoke and ice rod can serve as an ice measuring stick, and (3) the vane meter will not measure the vertical component of velocity. The contact chamber of the vane type meter can be rotated to any position, so the binding post can be placed perpendicular to the axis of the yoke to avoid interference when using the top of the yoke to determine the under side of the ice.

The velocity distribution under ice cover is similar to that in a pipe with a decrease in velocity as the under side of the ice is approached (see figure 36). The 0.2 and 0.8-depth method is recommended for effective depths 2.5-feet or greater and the 0.6-depth method is recommended for effective depths less than 2.5-feet. It is recommended that two vertical velocity curves be defined when an ice measurement is made at effective depths greater than 2.5-feet to determine if any coefficients are necessary to convert the velocity obtained by the 0.2 and 0.8-depth method or the 0.6-depth method to mean velocity. Normally the average of the velocities obtained by the 0.2 and 0.8-depth method gives the mean velocity but a coefficient of about 0.92 usually must be applied to the velocity obtained by the 0.6-depth method to convert it to mean velocity.

The rod or cable supporting the meter should be against the upstream edge of the hole when measuring the velocity, to keep the meter as far upstream as possible so it will be away from any effect the vertical pulsation of water in the hole may have on it. The current meter should be exposed as little as possible to the cold air during the course of a current meter measurement. Care should be taken to see that the meter is free of ice when observing the velocity.

If there is partial ice cover at a cross section, the procedure described above is used for the portion of the cross section that is ice

covered and the open water portion must be waded or measured from a bridge or cableway. The hydrographer must exercise care when there is a partial ice cover, that he does not go too close to the edge of the ice because that is where the ice will be the thinnest.

Measurement of deep swift streams

Part 5.1.4

Measurement of deep swift streams presents no serious problems when a sounding weight of sufficient size is available and there is not an excessive amount of drift and/or ice flowing in the stream. However, there are times when it is necessary to alter our normal stream gaging procedures when gaging deep swift streams. The six most common circumstances are listed below:

1. Able to sound; the weight and meter drift downstream.
2. Cannot sound; standard cross section available.
3. Cannot sound; standard cross section not available.
4. Cannot put meter in water.
5. Measurements during rapidly changing stage.
6. Series of measurements needed during a peak of short duration.

The procedures outlined for items 2, 3, and 4 above assume that there is a stable cross section. At stations with unstable channels it is necessary to decide on a procedure based on the situation at each station.

The procedures for each of the six items listed above are as follows:

1. The first item, when measuring where soundings can be obtained but the weight and meter drift downstream, is adequately covered on pages 43-58 of WSP 888. The use of tags on the sounding line and stay lines is also discussed on those pages in WSP 888.
2. The procedure to follow when measuring where a standard cross section is available, but where it is impossible to make soundings, is:
 - A. Determine the depths from the standard cross section.
 - B. Measure the velocity at the 0.2-depth.
 - C. Determine coefficients to adjust the 0.2-depth velocities to the mean velocity in the vertical on the basis of previous measurements made by the 0.2 and 0.8-depth method.

D. Compute the measurement in the normal manner using the depths from the standard cross section and the velocities as adjusted in step C.

3. The procedure to follow when measuring where it is impossible to obtain soundings and a standard cross section is not available is:

A. Reference the water-surface elevation before and after the measurement to an RP on a bridge or a driven stake or tree along the water's edge.

B. Estimate the depths and observe the velocity at 0.2 of the estimated depth. The meter should be at least 2.0-feet below the water surface. The actual depth the meter was placed below the water surface should be recorded in the notes. If an estimate of the depth is impossible just place the meter 2.0-feet below the water surface and observe the velocity there.

C. Make a complete measurement, including some vertical velocity curves, at a lower stage.

D. Use the complete measurement and difference in stage between the two measurements to determine the cross section of the first measurement.

E. Use vertical velocity curves to determine coefficients to adjust the velocities observed in step B to mean velocity.

F. Compute the measurement in the normal manner using the depths from step D and the velocities from step E.

4. The procedure to follow when measuring where it is impossible to keep the weight and meter in the water is:

A. Repeat step A in procedure 3.

B. Measure surface velocities by timing floating drift.

C. Repeat steps C, D, and then compute the measurement using steps E and F in procedure 3.

It should be remembered that just after the crest the amount of floating drift or ice will usually be greatly reduced and it may be possible to obtain velocity observations with a current meter. If this condition appears probable it would be best to omit the float measurement and make a current-meter measurement at a slightly lower stage.

5. During periods of rapidly changing stage, measurements should be made as quickly as possible to keep the change in stage to a minimum. The procedure to follow to speed up a measurement is:

A. Use the 0.6-depth method. The 0.2-depth method or the subsurface method could be used if placing the meter at the 0.6-depth creates vertical angles and thus wastes time because air and water depth corrections have to be made.

B. Reduce the velocity observation time to about 20-30 seconds.

C. Reduce the number of sections taken to about 15-18.

By incorporating all three of the above practices a measurement very often can be made in 15 to 20 minutes. If the subsurface method for observing velocities is used, then some vertical velocity curves will be needed later to establish coefficients to convert observed velocity to mean velocity.

It has been demonstrated that the discharge measurement error for a 45-second period of observation, using the 0.2-depth and 0.8-depth method of velocity observation, and depth and velocity observed at 25 locations is 2.2 percent. This means that two-thirds of the measurements made using this procedure would be in error by 2.2 percent or less. It has also been demonstrated that the error for a 25-second period of observation, using the 0.6-depth method of velocity observation, and depth and velocity observed at 16 locations is 4.2 percent. This slight increase in error due to using the short-cut methods suggested in procedure 5 is more than offset by the reduction in accuracy that would be caused by excessive change in stage during the time required to make a normal measurement.

6. The procedure to follow if a series of measurements is wanted during a peak of short duration is:

A. Take about 10 sections.

B. Take velocity observations at 0.6 depth.

C. Repeat velocity and depth observations at the 10 sections as often as possible throughout the period of the flood wave.

D. Develop stage-velocity and stage-depth curves for each of the 10 sections.

E. Compute the discharge corresponding to any stage from the curves thus defined.

Mean gage height of discharge measurements

Part 5.1.5.

The mean gage height of a discharge measurement is the mean height of the stream during the discharge measurement. The gage height is measured from the datum of the gaging station which is usually an arbitrary datum.

The mean gage height for a discharge measurement is one of the coordinates used in plotting the measurements to establish the discharge rating curve. An accurate determination of the mean gage height for a measurement is therefore as important as an accurate measurement of the discharge in providing the basic data for determining the stage-discharge relation.

Discharge measurements should be made during periods of steady stream stage if possible. This is not always possible especially during floods and on streams that are regulated. The computation of the mean gage height presents no problem when the change in stage is 10 centimeters or less, for then the mean may be obtained by inspection.

To obtain an accurate mean gage height, it is necessary to read the gage before and after the discharge measurement and to take readings from the recorder chart at breaks in the slope of the gage height graph during the time the measurement was in progress. At non-recording stations the only way to obtain intermediate readings is to have someone read the gage during the measurement or to stop during the measurement once or twice to go read the gage, and sometimes this procedure is necessary.

If the change in stage is greater than 10 centimeters it is usually necessary to weight the gage height readings to obtain the mean rather than obtain the mean by inspection of the available readings.

The mean gage heights during periods of constant slope of the gage-height graph and the corresponding measured partial discharges are used to compute the mean gage height of the measurement. The formula used is:

$$H = \frac{q_1 h_1 + q_2 h_2 + q_3 h_3 + \dots + q_n h_n}{Q}$$

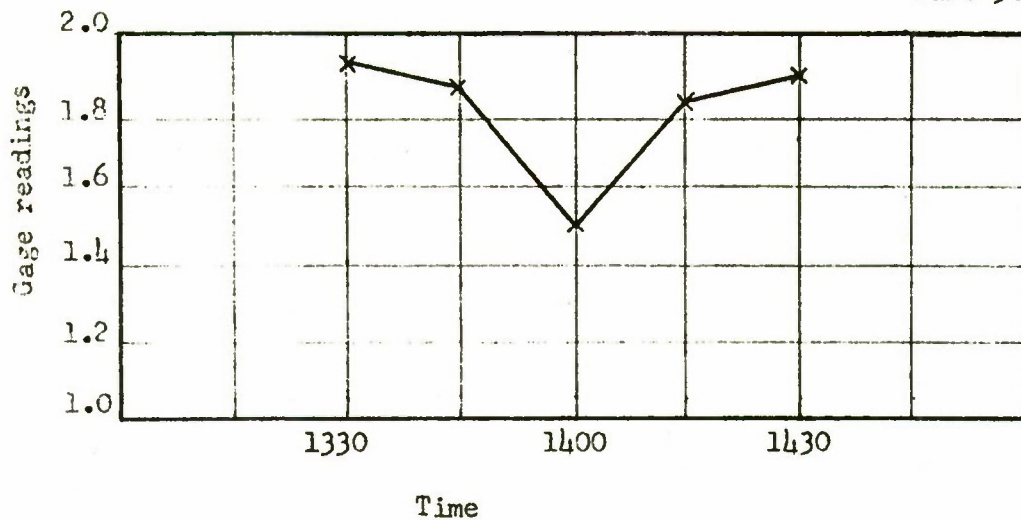
in which

H - Mean gage height

Q - Total discharge measured = $q_1 + q_2 + q_3 + \dots + q_n$

q_1, q_2, q_3 , etc. - Amount of discharge measured in time interval 1, 2, 3, etc.

h_1, h_2, h_3 , etc. - Average gage height during time interval 1, 2, 3, etc.



Time (1)	G.Ht. (2)	Ave. G.Ht. (3)	Q (4)	Column (3) x (4)
1330	1.94	1.92	16.10	30.91
1345	1.90	1.70	24.31	41.33
1400	1.49	1.67	20.99	35.05
1415	1.85	1.88	14.97	28.14
1430	1.92			
Total Q			76.37	135.43

$$\text{Mean G.Ht.} = \frac{\text{Total (3) x (4)}}{\text{Total Q}} = \frac{135.43}{76.37} = 1.77$$

Time (1)	G.Ht. (2)	Ave. G.Ht. (3)	Ave. G.Ht. minus base (4)	Q (5)	Column (4) x (5)
1330	1.94	1.92	.25	16.10	4.02
1345	1.90	1.70	.03	24.31	.73
1400	1.49	1.67	.00	20.99	.00
1415	1.85	1.88	.21	14.97	3.14
1430	1.92				
Total Q				76.37	7.89
Base 1.67					

$$\text{Mean G.Ht.} = \text{Base} + \frac{\text{Total (4) x (5)}}{\text{Total Q}} = 1.67 + \frac{7.89}{76.37} = 1.67 + .10 = 1.77$$

Figure 37.--Computation of weighted mean gage height.

Figure 37 shows the computation of a weighted mean gage height. The graph at the bottom is a reproduction of the gage height graph during the discharge measurement. The upper computation of the mean gage height in figure 37 shows the computation using the given formula. The lower computation has been done by a short-cut method to eliminate the multiplication of large numbers. In this method after the average gage height for each time interval has been computed a base gage height is chosen which is usually equal to the lowest average gage height. The difference between the base gage height and the average gage height is used to weight the discharges and when the mean has been computed the base gage height is added to it.

If a discharge measurement is made a considerable distance from the gage during a period of rising or falling stage, the discharge passing the gage at the time the measurement is made will not be the same as the discharge at the measuring section because of the effects of channel storage between the measuring section and the gage.

A correction for the channel storage may be applied to the measured discharge by adding or subtracting from the measured discharge a quantity equal to the product obtained by multiplying the area of the water surface between the measuring section and the gage by the average rate of change in stage in the reach. Below is the formula for correcting discharge for the storage effect during a changing stage:

$$Q_A = Q_M \pm WL \frac{h}{t} \quad (1)$$

in which

Q_A - Discharge going over the control

Q_M - Measured discharge

W - Average width of stream between measuring section and control.

L - Length of reach between measuring section and control.

Δh - Average change in stage in the reach L during the measurement.

Δt - Elapsed time during measurement.

It is necessary to set a reference point (RP) at the measuring section and determine the water surface elevation before and after the measurement in order to compute Δh . If the measurement is made above the control, the correction will be plus for falling stages and minus for rising stages; if made below the control, it will be minus for falling stages and plus for rising stages.

The following example illustrates the procedure for correction of channel storage:

Meas. made 0.6 km upstream = 600 meters
Average width between measuring section and control = 15 meters
Change in stage at control = +0.7 meters
Change in stage at measuring section = +1.1 meters
Readings taken at measuring section from a reference point
before and after measurement.
Average change in stage = $0.7 + 1.1 \div 2 = 0.9$ meters
Elapsed time during measurement = $1\frac{1}{4}$ hours = 4500 seconds
Measured discharge = 85 m³/sec

$$Q_A = 85 - 15 \left(600 \frac{0.9}{4500} \right) = 85 - 1.8 \text{ (use 2.0) } = 83 \text{ m}^3/\text{sec}$$

It is also possible to adjust a measurement for the storage correction by computing the time of travel of the flood wave from the measuring section to the control or vice versa, and then adjusting the gage height for the travel time to correspond to the measured discharge. The flood wave velocity is generally assumed to be 1.3 times the mean velocity for the measurement.

The travel time is computed by the following formula:

$$T = \frac{L}{1.3 V_m} \quad (2)$$

in which

- T - Time of travel of the flood wave between the measuring section and the control (in seconds).
- L - Length of reach between measuring section and control.
- V_m - Mean velocity of measurement.

In applying the time adjustment subtract the time of travel correction from the observed time at the gage if the measurement is made either below the gage on a rising stage or above the gage on a falling stage; and add the time of travel correction to the observed time at the gage if the measurement is either below the gage on a falling stage or above the gage on a rising stage.

The relationship between mean velocity and the velocity of the flood wave is uncertain in many cases and for this reason formula (1) is preferred to formula (2).

The proper coordination of the gage height and the discharge because of the amount of change in stage is a separate and distinct problem from that of making adjustments due to variable slopes that are caused by changing discharge; therefore the relation of stage to discharge at the time a measurement is made should be determined before adjustments due to variable slopes are made.

Accuracy of current meter measurements

Part 5.1.6

A discharge measurement is subject to three principal sources of error: personal, instrumental, and method.

PERSONAL ERROR

Personal errors are those made by the hydrographer in reading the instruments, counting the revolutions, and in making biased observations by reading high or low consistently. Many factors contribute to such errors: weather conditions, traffic, the hydrographer's mental attitude, inadequate training, and morale. These errors cannot be controlled but they can be minimized by proper training, by creation of good employee morale, and by instilling a pride of accomplishment. Personal errors cannot be evaluated but they are considered small.

INSTRUMENTAL ERRORS

The kinds of instruments used, the accuracy of their calibration, and their condition affect the discharge measurement. Instruments used in making discharge measurements include the current meter, the timer, the depth indicator, and the width indicators.

The current-meter error is caused by defects in the meter and by stream turbulence. Turbulent water affects the revolution-velocity rating of the meter which is based on towing the meter in still water. The instrument error due to rating the meter in still water and operating it in turbulent flow is difficult to evaluate. A comparison of the results of velocity observations made by the Price current meter and Ott current meter agree within 1 percent. Because the Ott meter tends to under-register and the Price meter tends to over-register in turbulent flows, these comparisons indicate that the effect of turbulence in measurement of streamflow is very small.

The errors introduced by the other instruments are believed to be even smaller than those introduced by the current meter. There is no way to evaluate the instrumental error but most investigators feel it is no greater than 1 percent.

METHOD ERROR

The method error is made up of three components:

1. The error due to the assumption that the mean of the velocity observations at 0.2-depth and 0.8-depth equals the mean in the vertical at the points of observation during the time period of observation (velocity error).

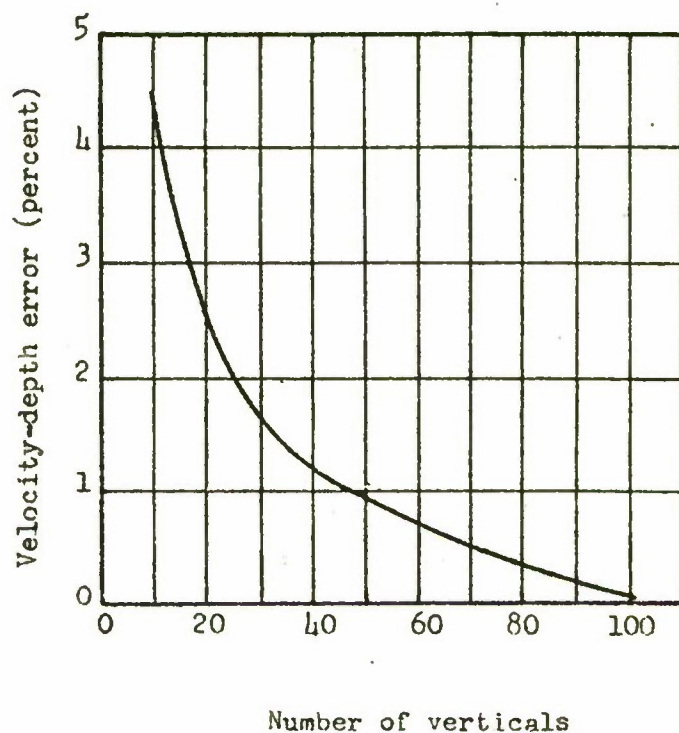
2. The error due to the assumption that the mean of the velocity observations at 0.2-depth and 0.8-depth at one location does not vary with time (velocity pulsation error).

3. The error due to the assumption that the velocity and depth vary uniformly from one observation to the next (velocity-depth error).

The velocity error has been evaluated empirically. Comparisons were made of the discharge at 100 different stream sites computed from velocity observations at 11 points in each vertical, and the discharge computed from the velocity observed at 0.2-depth and 0.8-depth at these same verticals. The standard error determined by the comparison was 1.5 percent. The standard error for the 0.6-depth method determined by this comparison was 3.1 percent.

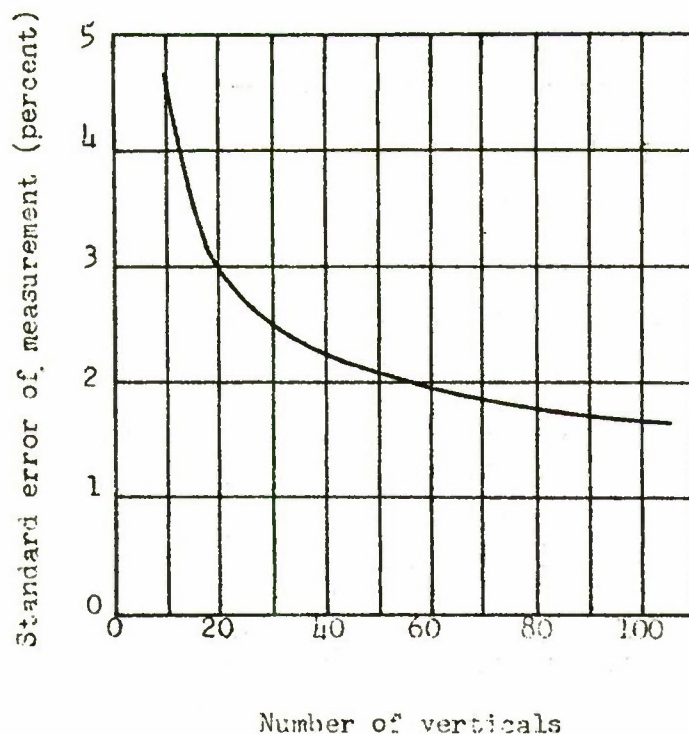
The velocity pulsation error is related to the time period of observation of the velocity at a point. The error was evaluated for a sample of 23 streams by comparing the mean velocity at a point for short-time periods with the mean for a 2-hour period. The standard error when individual velocities are observed for a 45-second time period, and the 0.2-depth and 0.8-depth method of velocity observation is used at n verticals is equal to $4.3/\sqrt{n}$ which means for a measurement with 25 verticals the standard error is 0.9 percent.

The velocity depth error is a function of the number of locations at which observations are taken. The error was evaluated at 130 stream sites by comparing the discharge computed from observations at 100 verticals per site with the discharge computed from observations at fewer verticals. The relation between the velocity-depth standard error and the number of verticals is shown in the following graph (assuming no error for 100 verticals):



TOTAL ERROR

Assuming that the various standard errors are independent, the total error is equal to the square root of the sum of the squares of the component errors. The errors as given are in terms of the standard error of discharge in percent of mean. The total current-meter measurement error exclusive of personal error is given on the following graph for a 45-second period of observation and the 0.2-depth and 0.8-depth method of velocity observation and various numbers of verticals.



According to this relation, if the velocity and depth are observed at 20 or more locations in the cross section, the error in the total discharge is expected to be less than 3 percent for two-thirds of the discharge measurements. The error would be slightly higher if the 0.6-depth method of velocity observation were used.

Results given here are based on data from cross sections with depths greater than 2.3-feet and velocities greater than 0.3-feet per second. Measurements in sections of smaller depth and of lower velocity will be less reliable.

Gaging station operation

Part 6.0

The operation of a gaging station involves four main objectives: (1) the collection of systematic and accurate records of stage, (2) the making of a sufficient number of discharge measurements to establish and check the relationship between stage and discharge, (3) the collection of hydraulic and hydrologic data concerning the stream such as bankfull stage, water temperature, changes in channel geometry, flood plain characteristics and so forth, and (4) the maintenance in a safe and proper conditions of all instruments and structures used in the collection of data.

The subject of gaging station operation has been divided into four categories and each will be discussed in turn:

1. General information
2. Field work
3. Gaging station maintenance
4. Safety

General information

Part 6.1

When a gaging station is established three types of information should be recorded:

1. A description of the gaging station structures and control.
2. Description of the drainage basin, including an inventory of regulation and diversions in the basin.
3. Detailed channel and flood plain characteristics in a reach including the gage.

The first two types are included in the field station description. The third is described separately.

Field station description

Part 6.1.1

The information concerning the physical makeup and necessary equipment and structures at a stream gaging station is called the field station description. The various headings to use on the field station description along with a description of the information needed under each heading is printed on the back of USGS form 9-277, Description of gaging station (see part 6.2.2.A). The field station description should be revised whenever any major changes are made at the station or in the hydrology of the basin.

The essential requirement of good records of stage and streamflow is that the field work be performed accurately and conscientiously. The streamflow data will only be as good as the field work that goes into it because the field data is the basis for the computation of streamflow records. Without the data collected in the field it would be impossible to compute streamflow records.

The hydrographer is given considerable responsibility when he undertakes a stream gaging trip and it is up to him to be certain he performs his duties in the manner in which he has been trained and that he does the best job possible under existing circumstances.

The first step necessary for the collection of accurate field data is that the hydrographer be adequately prepared for the field trip. By being adequately prepared means that the hydrographer has all the information necessary and all the equipment he will need and that the equipment is in good operating condition. The hydrographer should make any necessary repairs to his equipment immediately after he returns to the office from a field trip so that he will be prepared for the next field trip or an emergency trip he might be called on to make.

The following list of equipment needed for current meter measurements may serve as a guide to the hydrographer in preparing for a field trip:

1. Current meter
2. Stop watch
3. Headset, battery, wire, and connection plug, or electric counter instead of headset.
4. Notebook, note sheets, and pencil
5. Tag-line, or metallic tape
6. Wading rod, wire, and connection plug
7. Waders or boots
8. Sounding weight, weight hanger, and pin
9. Sounding reel with connector, and connection plug
10. Cable car puller
11. Crane, Bridgeboard, or handline
12. Counterweights for bridge crane
13. Field station description for each station to be visited
14. Copy of the latest rating curve for each station
15. Supply of note forms, pencils, etc.
16. Spare recorder clock
17. Spare paper rolls, recorder ink, and recorder oil
18. Extra meter pivots, set screws, hanger screws, meter oil
19. Wing nuts for sounding reel studs
20. Thermometer
21. Keys
22. Current meter rating tables
23. Hand tools (screwdriver, pliers, hammer, etc.)

Normally when a hydrographer visits a gaging station, he performs the following functions in this order:

1. Inspects the gage house and other structures to be certain no damage or vandalism has occurred since the last visit.
2. Inspects the gaging station control to determine if any visible changes have taken place or to see if there are any obstructions on the control.
3. Services the water stage recorder. Reads all the reference gages, outside and inside, and records the readings on chart, removes the chart, checks the action of the reversal mechanism, winds the clock, fills the pen, flushes the intakes or cleans the well by hand, and makes any necessary repairs to the instruments at the station.
4. Makes a discharge measurement. The type of measurement will depend on the amount of discharge, the time of the year, and the physical facilities at the station.
5. Reads all the reference gages at the station again and records the readings on the chart and on the front sheet of the current meter measurement notes. He makes sure everything is operating properly (is the pen down?) and locks the station properly.
6. When he gets back to the truck he makes an inventory of the equipment to make sure he hasn't left anything at the station.
7. The measurement is computed before the hydrographer leaves the station, and is plotted on the current rating curve. If more than 5 percent away from the curve he should check for reasons why and if none are apparent he must make a check measurement.

Channel and flood plain characteristics

Part 6.2.2

Information on the channel and flood plain characteristics helps to develop a better understanding of open channel hydraulics and morphology and adds greatly to the available knowledge of streams.

The following data are to be collected:

1. A topographic map of the reach of valley that includes the gage with features such as pools, riffles, channel alignment, roads, power lines, fence lines, and the extent and topography of the flood plain.
2. Two or more channel cross sections permanently referenced.
3. A channel bed profile.
4. Photographs to give a complete pictorial record of the reach.
5. Description of flood-plain soils, rock outcrops and size and kind of material in channel bed and banks.

Forms

Part 6.2.2.A

It has been stated previously that streamflow data is only as good as the field work that went into collecting the basic data. The field data should be recorded in clear and legible form so that it is easily interpreted. No matter how accurate data is, if it is not recorded in a manner that can be easily understood and used it is of little value. The USGS has a complete set of forms for use in recording field data and if the data collected is legibly recorded on the proper form there should be no difficulty understanding field notes.

The following forms are used to record observations made in the field:

No.	Description
DI-8	Observations of gage height (book for observer).
9-176	Gage height card (for observer).
9-176C	Inspection of water-stage recorder (card).
9-275	Discharge measurement notes (comes in several different forms designated by the letters a, b, c, etc.).
9-276	Level notes.
9-277	Description of gaging station - outline on reverse side.
9-278	Cross-section sheet.

In addition, there are several forms used for indirect measurements. These will be discussed in a later training course.

The first thing a hydrographer does when he arrives at a station is to inspect the gage house and other structures that are part of the gaging station to be certain that everything is in good condition and that nothing has been disturbed by unauthorized persons. If any damage has occurred at the station the hydrographer should make whatever temporary repairs are necessary. He should also note the extent of the damage and report it to his supervisor in writing.

The hydrographer should then inspect the gaging station control and fill in on the front sheet of his measurement the conditions that exist at the control. It is important to note whether the control is obstructed by logs or debris and the amount and extent of any weed or moss growth on the control. If there is ice in the stream, the type, location, and amount of ice should be recorded. No changes should be made to the control conditions until after the discharge measurement is completed. If obstructions are removed from the control before the measurement is made, the stage will start to drop which means the pool behind the control is draining and there is no easy way to determine when the pool has reached equilibrium.

Next the hydrographer should read the reference gages and service the water stage recorder. It is important that all the gages be read as found before any changes have been made. The reference gage readings, watch time, date, name of station, and hydrographer's name should be recorded on the recorder chart and the front sheet of the measurement. When the reference gages have been read a mark should be made on the graphic recorder chart by moving the recorder float pulley from one side to the other a small amount for recording the actual time shown when the chart was removed.

If the clock on a graphic recorder is found stopped, indicate exactly on the chart where the pen was found and if possible show the direction the pen was traveling. If the clock is stopped it is usually a good idea not to make an inspection mark on the chart because the length of the recorded line the pen is tracing may represent the range in stage during the clock stoppage.

After the inspection has been completed, then the necessary repairs and changes can be made such as flushing the intakes, changing charts, winding clocks, and so forth.

As the recorder chart is removed it should be inspected very carefully for any indication of malfunctions such as flat periods, sudden vertical lines, stoppages, or any obvious trouble which would call for action before leaving the station. The chart should be dated or the number of days of record counted to determine if there is any lost record or excessive corrections for time. If there has been lost

record during a rise it is important that the peak stage of the rise be determined. It may be necessary to find a high water mark in the well and reference it to gage datum to determine the peak.

After the removed chart has been inspected the remaining supply of charts or a new supply of charts if needed should be set on the recorder. The reference gages and watch time should be read and the readings recorded on the new chart and on the measurement front sheet. The date, name of the station and hydrographer's name should also be recorded, and an inspection mark made on the chart.

Next the hydrographer makes a discharge measurement. After the measurement the hydrographer removes any obstructions from the control. He should record the stage of the stream after the obstructions have been removed and the pool has drained and this stage can be used with the measured discharge to check the stage-discharge relation. Then he makes certain that the water stage recorder has operated properly during the time he was making the measurement. Then he reads all the reference gages and his watch, makes an inspection mark on the chart, and records his readings on the chart and the front sheet of his measurement notes.

Discharge measurements

Part 6.2.2.C

One of the essential points to remember concerning discharge measurements is to measure conditions in the stream as they are found without making any changes at the control. This does not mean that weeds or rocks or other obstructions cannot be removed from the selected measuring cross section or that a section cannot be prepared by building dikes to cut off dead water and shallow flows in the cross section. However, algae, debris, ice or any other obstruction on the control that can be removed should not be removed until after the measurement is completed.

The essential part of the collection and recording of field data for a discharge measurement is to be certain that complete and accurate information is obtained. Following the measurement the front sheet of the measurement should be completed. This sheet usually contains most of the supplementary information that is needed concerning the measurement.

Most of the items on the front sheet of the measurement are self-explanatory. The only item that might need explanation is the last one: gage height of zero flow. The gage height of zero flow is the stage of the lowest point on the low-water control and is helpful in determining the shape of the rating curve at low discharges. The gage height of zero flow is determined by measuring the depth at the deepest point on the low-water control and subtracting that depth

from the gaging station gage height at the time of the depth observation. The gage height of zero flow can only be obtained when it is possible to wade the stream at the low-water control but it should be obtained frequently on natural controls. The point of zero flow for artificial controls should be determined by levels.

If there has been more than 10 centimeters change in stage during the measurement it is important to obtain from the recorder gage height readings that will be needed to compute the mean gage height of the measurement.

Gaging station maintenance

Part 6.3

Maintenance is defined as the upkeep of property and equipment. Therefore, the purpose of gaging-station maintenance is to keep the structures, equipment and instruments in first-class working or operating order. Any malfunction of any part of a gaging station will result in either the loss of accuracy, the loss of record, or both.

There are two types of maintenance, namely, (1) preventive maintenance, and (2) emergency maintenance. The first type can be performed under preconceived plans and schedules while the second type, emergency maintenance must be performed in most cases without appreciable advanced warning or planning.

Preventive maintenance includes any activity that will extend the life or increase the usefulness of the gaging station, such as painting, replacement of damaged or badly worn parts or other minor repairs, checking wooden platforms, saddle blocks, sills, and A-frames for rot, checking and adjusting cableway sag, checking and tightening clipped cable connections, checking walkways, platforms, and cable cars for needed repairs, repairing or brushing cableway cross sections and other cross sections at which discharge measurements are made, and checking cableway anchors to make certain anchor bars and connections are in good condition and not covered with debris. The hydrographer should be furnished a "check list" to follow so that nothing will be overlooked.

Emergency maintenance includes any activity necessary to put a gaging station back into operation after an act of vandalism, damage by high water or by other causes, or to make immediate changes at a gaging station to meet a specific need resulting from an unforeseen situation. Usually this type of maintenance must be performed at once, as soon as the need arises, or some temporary steps taken until the work can be performed properly.

The hydrographer may not have with him all the tools and materials needed to perform emergency maintenance when such work is found to be necessary. He should attempt to put the gage back into operation on a temporary basis, however, and notify his supervisor of the situation giving estimated list of materials needed and approximate cost of repairs. If the damage is minor and repairs can be made on the spot, this should be done.

In general, the same procedures should be followed in the performance of maintenance as are followed for construction. Maintenance is just a minor construction job. The real difference is that maintenance work might be performed by a one-man party without advance notice. Maintenance work should be performed in a workmanlike manner and as safely as construction work.

Safety

Part 6.4

It is the policy of the WSS to provide a safe environment for employees and for the public when using WSS facilities, to seek out and correct unsafe conditions, to eliminate unsafe acts through education and training, to make safety an integral part of every task, to make accident prevention the responsibility of each employee and of each supervisor, and to make safety an essential part of the operations of the WSS.

It is the responsibility of all supervisors to see that prescribed safety precautions and instructions are observed in their work areas. Supervisors are responsible for training their employees to work safely, correcting unsafe acts and conditions, investigating and reporting all accidents, and taking other action necessary to insure safety and the protection of property.

Each employee is responsible for insuring his own safety and, wherever possible, that of his fellow employees and for reporting accidents and injuries promptly to his supervisor. He is also responsible for observing all safety precautions and adhering to all written and oral safety instructions.

Personal safety

Part 6.4.1

The hydrographer must consider his personal safety when preparing for a field trip. There are many safety checks of his personal equipment he should make before he even begins a trip.

The first item to be considered is clothing. The type and amount taken will depend on the weather that can be expected but it is always better to take more than probably needed. It is also important to have a complete change of field clothes in case the clothes being worn accidentally become wet. Good rain gear, a jacket with a hood, and good footwear are the three essentials of field apparel.

The following additional items should be part of the field man's safety equipment:

- First aid manual
- First aid kit
- Snake bite kit
- Life preserver
- Hard hat
- Ice creepers for boots and waders
- Fire extinguisher
- Flashlight
- Rope
- Pocketknife-Boy Scout type with sharp blade, awl, screwdriver
- Wooden matches in a waterproof case

Hydrographers should be familiar with mouth to mouth artificial respiration and should carry with them a wallet size card with instructions on the use of this method.

Field men should leave a detailed itinerary with their supervisor before starting out on a trip and if the itinerary is revised during the course of the trip, the supervisor should be notified by mail promptly. An itinerary is a long life line that can save a hydrographer's life in an emergency. The itinerary should include which stations are to be visited each day and where the hydrographer expects to spend each night. In addition, if a day's work takes a person into isolated country, it is a good idea to let the people at the place where he is staying know where he will be that day and when he expects to be back. If he is not back within a reasonable time of his expected arrival, the proper authorities can be notified and they will know where to begin looking.

Discharge measurements should not be attempted or continued during a lightning storm when the storm is directly overhead. The hydrographer should remain in his vehicle during such storms.

Prevention of Accidents While Wading

Part 6.4.2

The relatively large number of measurements made by wading in comparison with those by other methods and the wide range of conditions under which wading is done, together point up an accident potential.

Fundamental Policies

Part 6.4.2.A

1. All field personnel must have at least a fair degree of swimming ability. Caution.--This ability must not be allowed to result in overconfidence and the taking of unnecessary risks.
2. Wading should not be attempted if depths, velocities, and other factors and conditions are suitable for satisfactory use of other methods. Measurements made under conditions necessitating unusual physical strain and discomfort or preoccupation with the problem of maintaining position and balance may be subject to personal errors causing the results to be less dependable than those obtained by other methods.
3. Wading should not be attempted at the serious risk of disaster to personnel or expensive equipment, even though other methods would be less satisfactory.
4. Any rule of thumb for expressing limiting flow conditions for wading, such as depth x velocity = 10, must be used with caution. Such a criterion must be modified by many factors peculiar to the site and to the season of the year, as well as to personal factors relating to the individual concerned.
5. Prevention of accidents is, of course, the primary objective of a safety program. But familiarity with methods of escape and survival, as well as first-aid techniques, must be stressed to minimize the results of the inevitable accident.

Elements of a Wading Safety Program

Part 6.4.2.B

A broad outline for a safety program for wading activities should include at least the following general headings:

1. Proper safety equipment.
2. Identification of hazards and briefing on how to avoid or cope with them.
3. Routine safety procedures.
4. Instructions for specific sites and trips.
5. Field exercises in water safety.

Safety Equipment

Part 6.4.2.3.1

The articles of footgear and clothing customarily worn and the more-or-less standard equipment used in wading activities all have an important bearing on accident prevention and are considered in this section along with some of the conventional items of water-safety equipment.

1. Waders and boots.--Waders in particular should be rather loose fitting, even after allowance has been made for heavy winter clothing and socks or "pacs" for footwear. In addition to meeting the obvious requirements as to shoe size, the waders should be fitted in accordance with the individual's inseam, outseam, and seat measurements. This is to permit more freedom of action with less fatigue, to allow a longer stride to retain or regain balance, and to facilitate shedding in case an accident in deep, swift water makes such action necessary for escape. Recent experience demonstrates that boots or waders are difficult to remove in the water. Also, boots or waders are not the handicap to swimming that one might assume them to be.

2. Appropriate and properly fitted clothing.--As general principles, clothing - particularly outer garments - should be relatively loose fitting but not bulky, and as light in weight as is required for a fair degree of comfort. Garments should not bind or restrict movements when dry and should have a minimum of such tendency when wet. Stretch, relatively porous material is better in this respect than tightly woven nonstretching fabric. Fastenings should work freely. Outergarments worn with waders should be short.

3. Ice creepers (or their equivalent).--These are devices clamped or strapped on the shoe of boots or waders to increase traction used on steep or icy banks and on rocky or smooth and slippery streambeds, ice creepers will do much toward eliminating slips and falls. In addition, the feeling of surefootedness results in greater ability to resist the force of the current and generally in less tension and fatigue. For more complete protection, a design providing steel spikes or cleats for the heel as well as for the ball of the foot is recommended.

4. Taglines.--A strong tagline free from kinks should be provided, one which can serve to some extent as a lifeline. It should be well anchored on each bank if the section is difficult to wade.

5. Range pole or staff for exploration and balance.--Lightweight range pole, preferably jointed, is best for this purpose.

6. Life preservers and ropes.--As a rule, wading should not be attempted if there is any likelihood that a life preserver may be needed. Under certain circumstances, however, such as the possibility of quicksand or sharp dropoffs from ledge rock in the section, some type of life preserver should be used, particularly in the exploratory crossing.

Hazards and How to Avoid or Cope with Them

Part 6.4.2.8.2

The ability to identify hazards and accurately appraise their seriousness comes largely through personal experience in the specific area under consideration. Much can be done, however, through briefing. This section deals with generalized situations and conditions; a subsequent section suggests an outline for providing specific information at specific sites.

A. Unstable streambeds.

General rule: Allow plenty of freeboard at all times.

1. On exploratory crossing where quicksand or mire may be encountered, have light rope and wear a life preserver. Assign two-man party if in doubt.

2. For extremely soft bottoms, special "mud shoes" may be practical. These are adaptations of the "bear paw" snowshoe design constructed of lightweight rods or bars covered with woven wire webbing attached to the waders or boots.

3. For shifting sand, allow for scour during observation.

B. Rocky or slippery banks and streambeds.

Use ice creepers. Follow instructions under the following section on "Routine Safety Procedures" regarding techniques for maintaining balance.

C. Regulated streams.

1. Consult recorder chart or instruction for pattern of regulation.

2. Contact plant or gate operators before entering stream if warranted by situation or called for in instructions.

D. Flashy streams.

1. For rises already in progress, anticipate and allow for flow conditions at end of measurement.

2. In case of possible thunderstorm activity upstream in the basin, be on the alert for beginning of sharp rise. Glance frequently at outside staff if close by, otherwise select suitable reference point on stone or other object at hand. Watch upstream for sudden increase in amount of floating debris or foam.

E. Winter hazards.

Allow greater freeboard and higher safety factor in winter because:

1. Required extra clothing may impair freedom of action.

2. Prolonged chilling during measurements may seriously reduce muscular efficiency.

3. Immersion may bring on cramps or heart attack or have serious after-effects.

4. Shore ice and partial ice cover make for difficult entry and exit.

5. Partial ice cover often changes depth and velocity distribution.

Do not place too much dependence on field file data on wading stages.

F. Downstream hazards.

Allow an increased safety factor in selecting limiting wading stages close upstream from "traps", such as deep holes, waterfalls, high banks, ice, or other covered sections. Investigate downstream conditions before wading.

Routine Safety Procedures

Part 6.4.2.B.3

Inexperienced personnel should be given adequate personal instruction in the field on approved safety practices and techniques. Some safety procedures, which should become routine for difficult wading assignments are as follows:

1. Select section after consulting field file for limiting stages and reaches. Note and take into consideration any obvious changes in control or channel conditions that may affect the indicated limits, such as excessive scour, abnormal distribution of flow, backwater, and so forth.

2. Anchor tagline securely.

3. Leave equipment on shore until tagline is erected.

4. Proceed backward down steep banks until streambed is reached. This gives better protection from slipping and falling. Also it is easier to climb back out from this position in case of danger.

5. Use range pole as staff for exploration and balance. Sound the bottom ahead using range pole or other sturdy stick or pole graduated for depth. Wading rod is unsafe and unsuited for this purpose in critical situation.

6. Plant one foot firmly before moving the other. Place weight on ball of foot rather than heel. Plant the staff firmly before stepping, thus insuring at least two-point stability at all times.

7. Follow established route on subsequent crossings.

Instructions for Specific Sites and Trips

Part 6.4.2.B.4

Field files for each trip should include information and sketches, as required for individual stations, on:

1. Limiting stages for wading. May be shown by tabulation of previous measurements showing location, stage, maximum depth, and velocity.

2. Location of safe section. Standard cross section may be desirable in addition to plan sketch.

3. Regulation.

4. Specific hazards.

Field Exercises in Water Safety

Part 6.4.2.B.5

Actual field demonstrations potentially are the best means of teaching the basic principles and proper procedures both for wading-accident prevention and for escape and survival. Experience gained by an individual in a simulated emergency and the opportunity for safely testing his ability and endurance under handicaps of clothing, boots and equipment should do much toward lessening the chances of his "losing his head" and becoming panicky in a real emergency. Obviously, for maximum effectiveness, participation to the fullest extent practicable by all field personnel is required.

Some logical conclusions relative to wading safety are as follows:

1. Boots and waders fill rather slowly, actually having a distinctly buoyant effect when first overtopped. This is particularly true for hipboots with straps tightened around the tops and for waders snugly fitted at the top. If a position is quickly assumed in which air is trapped in the boots, preferably on the back with buttocks lower than head and feet, the resultant life-preserver effect should enable the wearer to keep afloat a considerable period of time with only a slight sculling motion of the hands and arms.

2. Swimming fully clothed and with boots is extremely tiring, however, and the other alternative of removing boots and partially disrobing often must be considered. The steps recommended are: (a) Take a deep breath, submerge and remove one boot, (b) inflate boot by taking a deep breath, submerging, and exhaling into the boot heels upside down in the water. Three breaths should be sufficient to make an effective life preserver, and (c) hold boot carefully without tipping as the other boot and outer clothing are removed.

3. Tests successfully completed with relative ease in still water with lifeguards and boats standing by should not be allowed to result in over-confidence. In a real emergency in a rapidly flowing stream the biggest problem may not be that of swimming or floating with clothing and waders, but of avoidance of downstream hazards, such as boulders, snags, whirlpools, ice cover, etc., which may be upon the accident victim in less time than it takes to accomplish a few feet of shoreward movement or to disrobe.

Prevention of Accidents in Cable Cars

Part 6.4.3

The cableway is one of the more common structures from which discharge measurements are made. Structurally, the cableway can be made safe.

Stresses in the cable itself may be analyzed within reasonable limits and manufacturer's inspection and testing assure reliable materials. The cable supports are subject to a rigorous stress analysis and subsequent safe design. The anchors are designed so that there is little or no danger of failure. But the accident-prone individual can find plenty of things happening to himself once he starts working from a cableway.

The prime safety rule in cable cars is never put your hands on the cable while the cable car is moving. The next most important rule is never to try to put the cable car puller on the cable while the car is in motion. The disregarding of these two rules is the major cause of most cableway accidents.

Certain measures that can be taken, aimed directly at the causes of accidents, are as follows:

1. Visually check the sag, cable clips, etc., before using the cableway. Use both hands to climb. Pull equipment to cable car by means of a rope or handline.
2. The gaging car should be locked to the cable support by a bar hook. Then the car can be unlocked from the platform without danger of its getting loose. The hydrographer can release the car from the hook once he is aboard, easily and without danger.
3. The cable car on long span cableways should be equipped with a smooth-acting brake which will enable a car to be slowed or stopped easily and without jolts.
4. The cable car should be equipped with a positive lock or a snubber, so that it may be held at any point along the cable, regardless of slope. This lock must be capable of ready application and in such a manner that there is no danger of catching fingers under the sheave.
5. A cable-car puller should be supplied which is positive in its action and grip and which will release the cable readily and without undue effort.
6. The top of the cableway supports should be at the same elevation, so that there is no danger of the cable car crashing into one of the supports when the car has been released at the other support.
7. During a discharge measurement, the hydrographer should keep a close watch for drift so that he may avoid any contact between the drift and his sounding line.

After these precautions have been taken, it is necessary to educate each man to the dangers inherent in the use of the cable car. Careful

explanation of the dangers involved and repetition of the warnings should have a salutary effect in making the field man safety conscious.

Prevention of accidents while measuring from a bridge
Part 6.4.4

The prime worry of our personnel when measuring streamflow from a highway bridge not equipped with sidewalks is the danger of being struck by vehicular traffic. When one considers present traffic speeds, truck loads, and the incidence of poor driving, it is apparent that a severe hazard to stream gagers exists at traffic bridges regardless of warning signs and barricades used. The answer to the problem of total accident prevention between traffic and stream gagers while working from bridges lies in one of the following solutions:

- a) If permissible and possible, install a walkway or tramway on the bridge structure so gaging operations can be conducted outside the traffic lanes.
- b) Install a cableway just upstream or downstream from the bridge.

Economic considerations frequently prevent the use of the foregoing solutions and gaging operations must continue subject to the traffic hazards.

During flood measurements from bridges, a hazardous condition that often exists is caused by floating or submerged debris in the water. A large tree carried along by high-velocity currents has considerable momentum and is almost sure to snag on the metering equipment if it comes against it. The usual result of snagging a fast-moving tree is the loss of sounding weight and meter when the suspension line breaks under the heavy stress placed on it. Remedial measures consist of:

- a) Use an assistant to the hydrographer. The assistant, who may be a local man hired for the job, has the primary duty of warning the hydrographer of approaching drift likely to strike the suspension line or metering equipment.
- b) Work from upstream side of bridge whenever possible. The hydraulic characteristics of bridge openings make the upstream side the one where greater accuracy of measurement can be attained and the approaching drift may be viewed with better judgement as to its danger.
- c) If a choice is permissible, wait until the stream has crested--much less drift is encountered on the recession side of the crest.

d) Keep lineman pliers handy to cut the line in case a snag is caught and loss of complete bridge crane appears imminent.

e) If a snag is caught, attempt to tow it over to the bank or other region of low velocity, by unreeling cable as necessary and pulling the rig rapidly along bridge walk. (Where measurement is made from within bridge trusses, this can't be done.)

f) Have a spare meter and weight handy when measuring under conditions hazardous to the equipment.

At bridges crossing major streams, power lines, telegraph lines, and occasionally gas or water mains are frequently strung along the sides of the bridge trusses in such a manner that they present a hazard to the stream gager using the bridge for a measuring structure. High-tension lines strung in close proximity to the bridge may also be dangerous. Inexperienced hydrographers should be warned of all hazards present, by: a) the older hydrographers who indoctrinate him; and b) a paragraph in the field station description describing the hazards.

If it is necessary to work from a bridge that has hazardous power lines, etc., a warning sign should be stenciled on some part of the bridge structure directly above the hazard so that the hydrographer would be sure to read it. The sidewalk or handrail is a good place for such a warning sign.

The foregoing hazards and the means suggested for minimizing accidents caused by them cover the more common dangers encountered in stream measurements from bridges. Precautionary measures are but part of the procedure to follow for accident prevention; the individual hydrographer must remain alert and think out a solution for all contingent hazards as they occur.

Accident prevention in making boat measurements

Part 6.b.5

The problem of accident prevention relates (1) to the safety of men engaged in making discharge measurements from boats and (2) the safety of other users of the river who may be endangered by a stretched tagline or an anchored boat. A discussion of some of the preventive measures that should be taken follows:

Education in good boatmanship and in the rules of navigable streams.--
Good boatmanship is largely a matter of using care, common sense, and courtesy. The first requirements are selecting the proper boat and

motor for the particular job and maintaining them in good, workable condition. The good boatman checks such items as oars, life preservers, buoyancy tanks, lights, and gasoline supply before he leaves the dock. He loads equipment along the sides of the boat and leaves a pathway down the middle. When in a small boat he remains seated while another member of the party is moving about, and he does his part in maintaining the boat on an even keel. He becomes familiar with the boat and learns what it will do and what it will not do.

Boat, boat booms, and motors.--Ample bow buoyancy and reasonably good lateral stability are very essential safety requirements in the selection of a boat. A boat that handles nicely under power and that can be turned sharply without capsizing usually will handle nicely when held by a tagline in fast water provided the load is distributed in such a manner that the boat maintains an even keel. It may be necessary to move the seat or lengthen the meter boom to achieve good balance, but the results are well worth the effort. A nose-heavy boat may become quite unmanageable in swift, turbulent water.

The boat boom used should be the new type described in part 5.1.1.D.3. The sheave end of the new boom retracts so the meter can be raised out of the water further so the hydrographer does not have to lean over the bow of the boat to clean the meter. The cross piece also has a rope attached to each clamp that holds the boat to the tagline so that in an emergency a tug on the rope will release the boat from the tagline.

The motor should be selected according to the size of the boat; both too little and too much power may be hazardous. Recent improvements in outboard motors provide a propeller-disengaging clutch and slip clutch instead of the old shear pin. Both of these improvements add greatly to the safety of boat measurements.

Selection and preparation of measuring sections.--Much can be done to contribute to the safety of boat measurements by careful selection and preparation of the measuring section. Many an obstacle that is of no importance during periods of low water may become of major importance during flood time. An obstacle that seems to be a longway downstream when the water is moving slowly will be very close when trouble develops and when velocities are high. Selection of measuring sections should be made with safety a paramount consideration, and the clearing of brush, trees, boulders, etc., should be done before the flood arrives. When it does arrive, good judgement may dictate that the measurement should not be attempted.

The hazards involved in measuring in the vicinity of canal siphons, pumping intakes, bridge piers, docks, dams, and other structures are often great. These hazards should be recognized and avoided, or special precautions should be taken.

Proposed safety measures and devices.--All occupants of WSS owned or operated watercraft 26 feet or less in length shall wear life jackets, vests, or buoyant type apparel.

WSS watercraft should be permanently and prominently labeled as to buoyancy, maximum horsepower, and maximum passengers or cargo equivalent.

Watercraft should have aboard and readily available a bailing device and a pair of oars.

The new type boat boom and the tagline reel with the brake are strongly recommended.

In final analysis, accident prevention depends to a great extent upon the attitude of men toward safety practices. Development of the safety outlook is of greater importance than the establishment of safety rules.

Discharge measurements from ice cover

Part 6.4.6

The key to safety in making discharge measurements under ice cover is frequent use of a 13-pound, 4½-foot long ice chisel, with a 2-inch or 3-inch wide blade to test the strength of the ice. Ice cover on a stream is not of uniform thickness such as often occurs on a lake or pond. The ice thickness on a stream varies because of the current, because of frazil ice irregularly lodged under the surface ice, because of snowdrifts, or because of ground-water seepage from the banks. Often the ice can be a foot thick in one place and less than an inch thick only a few feet away. Presence of snow will obscure such conditions, and the ice chisel should be used frequently to try the ice. The ice is considered safe when a solid blow with an ice chisel does not penetrate the ice. If the ice chisel goes through with one blow, the safe procedure is to back up and try another location.

For greatest safety the hydrographer should be familiar with locations of open-water wading sections for use as ice-measurement sections. Or he should examine lists of previous ice measurements to become familiar with any irregularities in the cross section.

Extreme care should be exercised when discharge measurements are made where there is a partial ice cover. The hydrographer should not go too close to the ice because the ice is usually not very thick at this point and there is always the danger of the edge portion breaking off due to the hydrographer getting too close to the edge.

Ice-cover discharge measurements are safe if made during low-water periods with proper ice-safety precautions. Venturing out on ice which is ready to move out or break up due to rising stages is a foolhardy adventure to be avoided. For medium and high stages, ice-dis-

charge measurements generally should not be attempted because of the danger involved and because of the probability that results from such measurements will have only a transient value.

In the event that someone does break through the ice, it is important that hydrographers be familiar with the proper way to get back on solid ice. The best way for a person to get back on the ice is to lay on his back and worm his way backwards onto solid ice.

Construction Safety

Part 6.4.7

A. Purpose of Safety in construction:

Safety, by definition, is the keeping of oneself and others safe, especially from danger of accident or disease.

The purpose of construction safety is to reduce the waste and suffering that accidents cause.

Accident prevention in construction is largely a matter of education, vigilance, and cooperation. Hard and fast rules alone will not insure safety on the job. This can only be secured by constant and careful attention on the part of the supervisor, with the cooperation of the workmen.

Men should be taught to think in terms of safety and taught never to take unnecessary chances.

B. Use of equipment:

1. Hard hats - Hard hats should be worn by all construction workers at all times while on the job. Metal hats should be worn in preference to composition hats, except on jobs where there is danger of coming in contact with electricity. Metal hats are superior to composition hats in resistance to impact.

2. Hand tools - All hand tools should be kept in safe working condition at all times. Defective tools should not be used. This includes tools with broken or split handles and wrenches with sprung or worn jaws.

Sharp-edged tools should be kept in first-class working condition, because a sharp tool is safer and more efficient than a dull one. Sharp or pointed tools should never be carried in pockets.

Hand saws should be kept well sharpened. A dull saw is likely to jump, and for this reason caution should be used when using the thumb to guide the saw in starting a cut.

Tools should only be used for the purpose for which they are intended; that is, never use a wrench as a hammer, a screwdriver as a chisel, or a file as a pry or a punch.

3. Ropes, cables, and chains:

a. Ropes - The use of cheap or very worn rope is dangerous. Whenever possible Manila rope should be used instead of sisal. Manila rope is stronger, easier to handle, and will not kink as badly as sisal rope. Care should be taken to avoid kinking, as this is one of the main causes of injury to Manila rope. Always dry rope after wetting. Rope should not be dragged unnecessarily along the ground, over rough surface, or across itself, especially if under tension. Sand and grit will work into the rope, cut it, and cause abrasion of the inner fibers.

Always use padding on sharp edges and corners to avoid cutting the rope.

Splices are safer and stronger than knots for permanent connections. The use of knots reduces the strength of rope as much as 50 per cent, while a splice reduces it only 5 to 10 percent.

At frequent intervals rope should be inspected throughout its entire length for cuts and abrasions. Also twist out rope at several points and look at the inside of the strands for internal wear.

Always use the proper size rope for the job to be done.

b. Wire rope (cable) - Wire rope should be inspected when installed, and running rope thereafter at least once a week and removed from service if significant damage is noted. Kinking is one of the most common causes of failure.

If running wire ropes are to render safe service, they must be lubricated regularly. Because running wire ropes are lubricated with oil, they should be kept away from fire or fire hazards. Even a slight burn will dangerously weaken the rope and render it unsafe for further use.

Tables for strength of wire rope should be obtained and consulted frequently.

c. Chains - Chains are less reliable than Manila or wire rope, as they usually break without warning. They may not show weakness but yet have small cracks or flaws.

When using chains, eliminate twist or kink before applying load. Do not jerk chain. Do not overload beyond safe capacity. Use correct fittings. Remember that steel chain does not always stretch before breaking. Do not use bolts or nails to fasten two links together. Replace chain when worn out or when showing fractures. A faulty chain that breaks while in use may cause injury to workmen and also loss of time.

Always remember to stay clear when using rope, wire rope, or chain to prevent injury if failure occurs.

4. Ladders - Ladders present one of the major hazards in construction work. Great care should be used in the selection of proper size and design of ladders for the use intended. Do not buy inferior ladders, and never buy or use a painted ladder. The paint may cover possible defects.

Portable ladders used on smooth or sloping surfaces should be equipped with non-slip bases or fastened at the bottom. It is always advisable to secure the top against slipping.

C. Special Techniques:

1. Shoring - The construction of gage wells and even of controls or cable anchorages generally creates a hazard because of cave-ins or the falling of loose material. Gage-well excavations, because of their greater depth and the wet material encountered usually present the greater problem.

Although not properly classed as cave-ins, the falling of loose material deserves mention. Loose boulders may be dislodged by heavy rains or by blasting or other construction activities. Pieces of rock ledges, near which gage-well excavations often are made, may give way under blasting. Adequate initial clearing when material is easily disposed of is an economical and safe practice.

Too often an excavation by hand or power methods is made with the expectation that the material will stand up without shoring. What initially may appear stable can produce cave-ins by excessive overburden of wet material near the excavation. The experienced man usually assumes the least stability for the material encountered through disposal of excavated material and through shoring. Early recognition of the need for shoring, and the use of sturdy well-braced

timbers is economical and safe. Provision should be made for "pinching-in" successive sets of shoring if the excavation is deep. Ample clear working space is important for easy removal of material as well as safety. Standard plans show acceptable methods of shoring; make-shift methods are usually costly. Evidences of impending failure of shoring usually is apparent. Inspection for excessive pressures should be second nature, and prompt steps should be taken to strengthen the shoring through additional bracing or by completely replacing the shoring. Substantial shoring is a small part of the excavation cost. In addition to insuring against fatalities it pays for itself in preventing lost time and duplication of work.

Having provided reasonably safe excavating conditions does not relieve the supervisor of further responsibility. One or more ladders should be available at all times, or other quick means of exit provided, in the event of trouble. If the excavation is in quicksand or heavy mud, see that workmen do not get themselves bogged down; boards to stand on and close attention to dewatering usually will improve the situation.

2. Scaffolding - The freedom of movement that comes from good scaffolding pays dividends in production as well as safety. Walkways should be ample in width and tread surfaces made as skidproof as possible. Cleats or carpeted surfaces, using burlap or canvas, are particularly desirable where wet concrete or mud is handled. A guard rail or hand rail is easily constructed and may save serious injury. Ladders generally are used to reach scaffolding and should be well built and well placed. Where scaffolds are used at more than one level, care should be exercised to prevent injury through falling objects. Carelessness that is bred through repeated use is the biggest single hazard in the use of scaffolding.

D. Flammables and explosive gases:

1. Use - In construction, acetylene, oxygen, gasoline, paints and other flammables are often used. It is particularly important to take extreme care when using any flammables. Explosive gases and vapors from flammable liquids may be ignited in any of four ways; spontaneous ignitions of nearby substances, generation or application of a flame, by a spark, or by excessive heat.

The use of open flames and smoking should be prohibited where explosive substances are used or stored.

Acetylene should never be used at a pressure of more than 15 pounds per square inch, as it is likely to explode above this pressure.

Never allow oil to come in contact with valve, regulator, or any other portion of oxygen apparatus or cylinder. A mixture of oil and oxygen is very explosive.

2. Storage - Flammable liquids and explosive gases should be stored in cool, well-ventilated, detached buildings of fire-resistant construction. Floors should be earth or concrete, and not of wood.

Rags, waste, burlap, or clothing should not be allowed to remain in storage building. Smoking should never be permitted in or near the building.

Flammable liquids should always be in closed containers; never store gasoline in a glass containers--when pressure builds up, the container will burst.

No open flame, grinding tools, or spark emitting devices should ever be used within the building in which acetylene is stored. Always store and use acetylene cylinders upright with valve end up.

Never drop a cylinder of explosive gas or place it where it will fall or be struck by another object. Knocks, falls, or rough handling are likely to damage the cylinder, valve, or fuse plug, and may cause leakage or result in an explosion.

E. Explosives:

It is sometimes expedient and quite often necessary to employ the use of explosives in the course of constructing gaging stations where part or all of the excavation is in rock.

The list of "don'ts" adopted by the Institute of Makers of Explosives, and the instructions furnished by manufacturers for making up primers and for handling and storage of explosive, if observed, are sufficient as a safeguard against trouble. These instructions and precautions should be reviewed on each occasion that blasting is required, particularly if blasting is done infrequently.

Of these instructions there are some which should be emphasized because they are the most probable sources of trouble:

1. If a considerable amount of explosives is to be used on a job, the bulk of them should be stored in a cool, dry place, out of the sunlight, and away from the job. The quantity expected to be used during the day's operation should be taken to a safe place closer to the job. Any not used should be returned to the main storage at the end of the day. It is extremely important that small amounts of explosives or caps should not be cached under a boulder or in a tree trunk where they are apt to be forgotten. These stray charges could be a contributory to an accidental explosion which could result in serious injury.

2. Detonators and explosives should be stored in separate containers and should be kept apart until the last possible moment. Primers should be prepared away from the storage place and should not be made up until the last possible moment before loading.

3. Any primers not used should be disassembled. It should be realized that the damage potential of the primer is greater than that of either the detonator or the explosive alone.

4. The dread of all blasting operations is the misfire. The handling of misfires is an extremely ticklish job and the book states that misfires should be handled only by a competent and experienced man. Since this is not always practical it seems that the best way to handle misfires is to eliminate them in the first place. This can be done.

Experience has shown that misfires rarely occur when using electric caps but occur frequently when caps and fuses are used. This indicates that electric caps prepared by a manufacturer are more reliable than the cap and fuse detonator made up in the field by hand. Electric caps should be employed exclusively as detonators. Another advantage in using electric caps is that it is possible to check out the current electrically before firing.

The handbooks cover the handling of misfires, but it might be beneficial to mention the ways of handling them:

1. The safest way to dispose of a misfire is to remove part of the stemming material and shoot the hole with another charge in an attempt to explode the missed charge. In a small-diameter hole the safest way to remove the stemming is to wash it out by means of a stiff rubber hose and a strong jet of water. It becomes apparent here why it is important to put the primer at the bottom of the charge.

2. Misfires can also be handled by drilling another hole far enough away for safe drilling but close enough that the explosion of the charge in the new hole will detonate the missed charge by propagation. Care must be exercised in location and direction of the second hole to avoid the possibility of striking the missed charge with the drill. This method often fails to explode the missed charge and results in throwing unexploded dynamite into the debris. For this reason it is desirable to locate the second hole in front or alongside of the missed charge, instead of behind it, in a hope that the unexploded dynamite will lie exposed and can be removed before clearing out the debris.

Any person, particularly an inexperienced one, who is going to have to handle explosives should be furnished with a handbook on blasting. These books show pictorially the recommended methods

of preparing primers and loading holes and also the methods that are not recommended. They contain other valuable information concerning the art of blasting.

Any office which has to do occasional blasting should stock a blasting machine and a roll of electrical wire suitable for blasting purposes. If these are stock items, part of the hesitancy in using electric caps will be overcome.

The person in charge of a blasting operation would do well to keep in mind the possibility of a misfire before loading the charge and then take every precaution to eliminate this possibility.

F. Vehicles:

1. Trucks and automobiles - Trucks should always be loaded so that the driver can see forward and to each side, and toward the rear. The load should be placed and secured in such a manner that there will be no danger of the load shifting or falling off. Care should be taken to insure that the safe load limit for the truck is not exceeded.

It is very important to use vehicles that are in good mechanical condition. Special emphasis should be placed on adequate brakes.

Whenever a truck or any vehicle is parked on a slope during construction, the wheel should be blocked to prevent rolling.

Always obey traffic laws when driving to and from the job.

G. Jobs that should never be done alone:

Any construction job of a hazardous nature should never be attempted alone. Some of these jobs are as follows:

- Loading explosives in holes.
- Working in an excavation.
- Working on ladders or scaffolding.
- Working with electric or pneumatic tools.

H. First Aid:

First aid is the art of giving quick and correct assistance to the sick or injured while medical help is being secured. Always keep in mind that this aid is only temporary and should never replace the treatment given by a physician.

It is vital that all men in a construction crew have a working knowledge of first aid, because accidents often occur in this type of work. Every member of the crew should be able to recognize the symptoms of heat exhaustion and sunstroke and be familiar with the proper treatment. A knowledge of the location of arterial pressure points is vital. If an artery is severed a man can bleed to death in a matter of minutes if the bleeding is not stopped. The symptoms of shock should be recognized and the treatment necessary should be known. Also it is vital to know the proper method of administering artificial respiration.

The following are the general rules to follow in case of injury:

1. Keep the patient lying down with the head level until the nature of his injuries has been determined.
2. Examine the patient for hemorrhage and cessation of respiration. These conditions take precedence in this order over everything else and demand immediate treatment.
3. Remove enough clothing to determine extent of injury. Do not remove any more clothing than is necessary so that the injured person can be kept as warm as possible.
4. Above all, do not let yourself get excited. Act quickly but efficiently.
5. Keep the patient comfortable.
6. Do not let patient see his injury.
7. Do not touch open wounds or burns with your fingers.
8. Never give an unconscious patient liquids.

Always remember to treat the most serious of the patient's injuries first. The order is hemorrhage, cessation of breathing, shock, and then the broken bones, wounds, etc.

It is very necessary to have on every construction job, regardless how small the job, an adequate first aid kit, including a snake bite kit. This kit should be located in a central location and every workman should know what it contains and where it is located.

I. Importance of safety in construction:

In every facet of life today we are becoming ever more impressed by the importance of continually being safety conscious. This is

especially true in the field of construction because of its inherently hazardous nature. Therefore it is extremely important to teach everyone associated with construction to think in terms of safety and never to take unnecessary chances. Without continued education, vigilance, and cooperation the rate of accidents would surely increase. To prevent this, each person on the job must realize this importance as a member of a team, for only through teamwork in all phases of construction can the ultimate in safety be achieved.

Prevention of accidents connected with
maintenance of stream-gaging facilities

Part 6.4.8

Non-maintenance of facilities must be considered as being extremely dangerous, inasmuch as such accidents probably will occur with absolutely no warning. The best way to prevent such accidents is to enforce a rigid schedule of preventive maintenance in combination with use of caution and common sense on the part of personnel. In addition to checking condition of, and making necessary repairs to existing facilities, preventive maintenance procedures should include actual changes in or additions to existing facilities if experience indicates such action is necessary to maintain safety standards. It should be standard operating procedure for hydrographers on routine field trips to note any unsafe conditions and, where possible, to make needed repairs even though they may be temporary in nature. When it is possible to make temporary repairs or when temporary repairs should be followed up immediately by permanent repairs, special trips should be scheduled to make such repairs. In addition, routine maintenance trips should be scheduled once a year to put all facilities in ship-shape condition.

Some of the more common causes of accidents due to non-maintenance of facilities, along with preventive maintenance procedures which should be enforced, are discussed below.

Gage houses and wells

Part 6.4.8.A

One of the more dangerous accidents in this category is one in which a man might fall into the well either by falling through a floor or trapdoor or falling from a ladder. As is generally the case, caution on the part of personnel is the best preventive procedure. However, certain additional precautions will help to eliminate accidents.

If a wooden floor is used in a house, timbers should be checked periodically for possible rotting, especially on the under side.

Bad timbers should be replaced as necessary. In this connection, it should be mentioned that often timbers may look sound but probing with a sharp object may indicate rotting. Wooden trapdoors should be installed with beveled edges so that if support timbers should fail, the trapdoor will not immediately fall through the opening. Rotten timbers should be replaced by concrete floors and steel trapdoors. Even with this precaution, however, the trapdoors should be inspected periodically to guard against weakening because of corrosion. If the trapdoors are not galvanized, some protection against corrosion can be supplied by proper painting of the steel.

The best safeguard against falling from a ladder, of course, is care on the part of personnel. However, to aid in getting on and off ladders, handholds should be provided at all doors. During rises, ladder rungs may get covered with mud and slime, causing a person who is wearing wet boots to slip while climbing up or down. Accordingly, ladder rungs should be cleaned periodically. Ladder supports should be inspected periodically to insure that the ladder is safe. In this connection, individual ladder rungs cemented into the wall should be discouraged in favor of built-up ladder sections because of the added safety feature of the side rails on the ladder type. Whatever type ladder is used, galvanized steel is preferable to timber. If built-up sections are used, galvanizing should be after fabrication.

It probably would be well to stress the fact, although it should be readily apparent, that personnel should not be moving around an open trapdoor in a gage house. Also provision should be made for holding a trapdoor in an open position when a person is climbing into or out of a well.

A gas mask should be worn when using an acetylene torch in a well to prevent poisoning from zinc-oxide fumes.

Safety features on structures

Part 6.4.8.8

Ladders and steps.--These should cover the entire range to be climbed, and rung or step spacing should be designed for shorter-than-average persons. Even those of average stature will appreciate the shorter step spacing when wearing heavy or water-proof clothing that reduces freedom of action. Do not lengthen or omit that last step at the bottom or at the top. Avoid use of wood whenever practicable.

Hand holds.--Provide hand holds particularly near the top above the last step.

Landing or loading platforms.--Every support frequently or customarily used for entering and leaving the cable car should be equipped with landing platform if floor of car is above shoulder height, or even if less than that height where ground slope is steep and surface provides unsafe footing.

Other supports, even though not ordinarily used for loading purposes but which are used occasionally for inspections, should be provided with platforms if car is higher than 15 feet-off the ground or conditions are such that entering and leaving the car are especially difficult.

Platforms should extend under or alongside the car a sufficient distance and at such height as to permit entering, and mounting equipment in the car, without excessive stretching or leaning out over space.

On tall towers or A-frames landings should be provided for each 25 - 30-feet of height.

Railings and safety cages.--Railings should be provided for all walkways and landings, and all loading platforms over 15-feet high, or lesser heights if conditions around the base of the structure are unusually hazardous.

Safety cages should be provided around vertical ladders or steps that are more than 25-feet high.

Cable car hooks.--These devices should be installed on all supports, regardless of height, regularly used for entering and leaving car. They should be available also on all high supports and on cableways with large amounts of sag, regardless of infrequency of use.

General provisions.--Avoid leaving unnecessary projections which might catch clothing or cause tripping and loss of balance. Cut off projecting ends of bolts around ladders, steps, railings, and platforms.

If practicable clear or remove from around the support and under the platform hazardous objects such as stumps, boulders, or depressions.

Safety techniques and practices

Part 6.4.8.C

Climbing.--Use both hands and every ladder rung or step. Look up instead of down if the height bothers you.

Avoid wearing loose or torn clothing that might catch on the structure or the cable car. Avoid extremely tight or bulky clothing as much as possible. Boots with composition soles give better footing on steps and platform under most conditions than leather or rubber.

Transferring equipment to and from car.--Do not attempt to climb with a load of equipment. Pull heavy or bulky equipment to platform or cable car by means of rope or handline.

Entering and leaving cable car.--Make sure cable car is held by hook. As an added precaution have car puller in position for braking action if needed.

Inspections.--Inspect structures periodically as to adequacy of safety provisions and maintenance needed.

Inspect timber A-frames at least annually for decay. This is especially necessary with respect to base of legs, ladder steps, and platform. A well-painted exterior is no assurance of safe condition. Use sharp instrument to reveal weaknesses the eye may not otherwise detect.

The prevention of falls from A-frames is, of course, only one phase of the overall accident-prevention program of the WSS. Actually, though, this specific problem deserves considerable attention; the accident potential is significant at the present time. Fortunately, however, since there need be few if any variable factors or circumstances over which the individual has no control, almost all accidents of this type can be avoided through a policy of providing adequate safety aids on all structures and of observance of approved safety rules.

Cableways should be designed and constructed according to instructions in USGS Circular 17. However, periodic inspections still should be made to insure that the structure is sound. Cable supports and anchorages should be inspected in order to determine any weaknesses. Anchorage U-bolts should be galvanized or protected by red lead. If timber A-frame supports are used, areas where one timber bears on another should be painted before assembling. When steel A-frame or H-beam supports are used, if it is feasible they should be galvanized after fabrication. Cable clamps should be checked periodically and tightened as necessary. Cable sag should be adjusted as necessary to correct for seasonal temperature changes. Ladders provided for ascending and descending cable supports should be kept in safe condition by painting as necessary and by replacing any rotten or corroded parts. All timber in cableway structures should be protected by periodic painting, checked periodically for soundness, and replaced as necessary.

Approach Walks and Stairs

Part 6.4.8.D

The same precautions listed previously concerning protection, inspection, and replacement of exposed timber and metal should be followed. High stairs should be provided with safety railings which must be kept in good condition. Otherwise an accident may be caused by having the railing give way when a person supports his weight on or against it. Where they are feasible, concrete stairs are preferable to timber stairs. In like manner, steel-grill walkways supported on steel I-beams (all steel to be galvanized) are preferable to timber walkways. Railings, properly maintained, always should be provided for walkways.

Miscellaneous

Part 6.4.B.E

In some cases, it is necessary for personnel to climb up and down steep banks in order to read outside gages. In such cases, handrails should be provided, and where necessary, steps should also be provided.

Many of the same safety regulations applicable to construction activities also apply to maintenance activities. Some of the more important safety practices which should be followed are listed below.

1. The work area should be kept free of obstacles.
2. The proper tool or equipment should be used for the job at hand.
3. Men working in a gage well should wear hard hats.
4. If deep excavations are made, shoring should be used.
5. A scaffold should be provided in a gage well whenever work is being done between the water surface and the gage-house floor.
6. When a gasoline-driven pump is used for pumping out a well, the pump frequently must be handled in an area of difficult footing; therefore, heavy pumps should be avoided whenever possible. Also gasoline or motor-driven equipment such as pumps and generators should not be moved while they are in operation. Care should be taken to make certain that exhaust fumes from gasoline motors do not discharge into a well while personnel are working in the well.

7. If it is necessary to use dynamite, only someone experienced in explosives should handle the job.

8. Ladders used for reaching high areas, such as a gage-house roof, should be in good condition and supported firmly in order to avoid slipping.

9. When a heavy object must be lifted, equipment that will furnish a mechanical advantage, such as chain hoist or block and tackle, should be used. In using such equipment, care must be taken to see that the object being raised or lifted such as a large A-frame, is held securely during the actual operation and that personnel in the area are not in position to be injured in case of failure of the equipment. Any such equipment used should be inspected for safety prior to use and any weaknesses should be repaired or replaced.

In summary, use of caution and common sense on the part of all personnel are the best safeguards against accidents. However, certain preventive maintenance procedures--including inspection, repair, and replacement--will eliminate most accidents caused by non-maintenance of facilities. Accidents during actual maintenance operations can be eliminated by having personnel follow certain standard safety rules such as those listed previously.

Motor vehicle safety

Part 6.4.9

Probably the most dangerous task a WSS employee has to perform is to drive his official vehicle. To reduce the accident potential it is important that the official vehicles be in good operating condition, properly equipped, and the hydrographers drive these vehicles in a safe courteous manner.

Before a trip is begun the following items should be checked by the hydrographer to be certain that the vehicle is in good operating condition:

Brakes	Glass
Steering	Mirrors
Tires	Oil level
Battery	Coolant level
Lights	Direction signals
Horn	Exhaust system
Windshield wipers	Heater

If any items are found defective they should be repaired or replaced immediately.

The vehicle should also be checked before being used to be certain it is properly equipped. The following items of equipment should be standard in every vehicle:

Seat belts	First aid kit
Tire chains	Flashlight
Tow Chain	Shovel
Booster cables	Jack and tools
Fire extinguisher	Windshield scraper
Flare	

Two other vehicle accessories that are recommended are windshield washers and the signalflasher that operates all four turn signals simultaneously. The windshield washers are invaluable in a light rain in dusty country or when the pavement is wet and the windshield is being sprayed by the vehicle ahead or by passing vehicles. The signalflasher is a valuable safety aid when it is necessary to stop, park, or work on or near a well-traveled highway. Some vehicles are equipped with permanently attached or portable flashing lights for this purpose and these lights are highly recommended where it is legal to use them.

Jeeps and Carryalls should be provided with a protective partition between the driver and the load in the rear so that in the event of a sudden stop, the load will be prevented from hitting the driver. Sounding weights and other heavy equipment should be strapped down so that they cannot move about.

Vehicles should not be overloaded and the load should be properly distributed in the vehicle. A larger vehicle should be used if the load is too great for a particular vehicle. Because of the desirability of having the sounding weights near the rear of the vehicle, it is good practice to have helper springs installed on the rear springs.

The vehicle can be in top operating condition and be properly equipped but if it is not driven properly in a safe, courteous manner this all goes for naught. If drivers would follow the rules of the road, the number of accidents could be drastically reduced. The following rules are listed here to emphasize their importance:

- a. Obey all motor vehicle laws.
- b. Don't speed.
- c. Keep the proper distance behind the car ahead.
- d. Don't pass when there is any doubt.
- e. Don't drive while sleepy.
- f. Realize the limitations of the vehicle.
- g. Use proper signals.

All hydrographers should be aware at all times of the need for employing safe driving practices.

Office procedures

Part 7.0

The first step in analyzing the stage and discharge data collected in the field is to prepare a stage-discharge relation curve on the basis of the discharge measurements. Then the daily mean gage height for each day is computed from the record of stage. The application of the daily mean gage height to a rating table prepared from the rating curve gives the daily mean discharge.

Rating curves

Part 7.1

Rating curves are used to establish the relationship between stage and discharge at a gaging station. The stage-discharge relation is defined by plotting the measured discharge as the abscissa and the corresponding gage height as the ordinate. A smooth curve is then drawn through the plotted points averaging the points as nearly as possible. A sufficient number of discharge measurements should be available, well distributed with respect to both stage and time, to define the rating curve.

The shape of the rating is a function of the geometry of the channel below the gaging station. The relation is generally concave downward on rectilinear coordinates; at medium and high stages it approximates a straight line on logarithmic coordinates.

Changes such as scour and fill in the control reach will cause corresponding changes in the stage-discharge curve. Discharge measurements are made as often as once a day, or once a month, or only several times a year, depending on the stability of the control, in order to define the current position of the rating curve.

To provide a convenient means of translating a record of gage height into a record of discharge, a rating table is prepared from the rating curve. The rating table shows the corresponding discharge in cubic feet per second or cubic meters per second for each tenth of a foot or centimeter of gage height.

Computation of daily discharge

Part 7.2

The first step in the computation of daily discharge is the determination of the daily mean gage height. When the change in stage is small the mean gage height for non-recording stations is determined by averaging the morning and afternoon readings. When the change in stage between readings is large, it is then necessary

to plot the readings with respect to time, draw a gage height graph through the readings, and treat the graph in the same manner as a graphic water-stage recorder chart in order to compute the daily mean gage height. The daily mean gage height for a station equipped with a graphic water-stage recorder is determined by graphical means. The daily mean discharge is obtained by application of the daily mean gage height to the rating table. If the range in discharge during the day is large, the daily mean discharge cannot be computed from the daily mean gage height because of the curvature in the stage-discharge relation. For this case the day is subdivided into periods and the mean gage height is computed for each period. The daily mean discharge is computed as a time-weighted average of the discharge for the periods used. The daily discharges are tabulated by calendar dates and the average discharge for each month and the year are computed.

If the stage-discharge relation is subject to change because of frequent or continual change in the physical features that form the control, the daily mean discharge is determined by the shifting-control method, in which correction factors based on individual discharge measurements and notes by hydrographers and observers are used in applying the gage heights to the rating tables.

At some gaging stations the stage-discharge relation is affected by backwater from reservoirs, tributary streams, or other sources. This necessitates the use of the slope method in which the slope or fall in a reach of the stream is a factor in determining discharge. Information required for determining the slope or fall is obtained by means of an auxiliary gage set at some distance from the base gage. At some stations the stage-discharge relation is affected by changing stage. For such stations, the rate of change in stage is used as a factor in determining discharge.

At some gaging stations the stage-discharge relation is affected by ice during the winter, and it becomes impossible to compute the discharge in the usual manner. Discharge for periods of ice effect is computed on the basis of the gage-height record and occasional winter discharge measurements, consideration being given to the available information on temperature and precipitation, notes by gage observers and hydrographers, and comparable records of discharge for other stations in the same or nearby basins.

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